Assessment of Domestic Appliance Noise

Thesis

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Thesis submitted by

Jeanette Rosamond Brooks

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Department of Engineering Mechanics
Faculty of Technology
Open University
Milton Keynes
England

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Abstract

The aims of this study were: (i) to identify the factors involved in eliciting a subjective reaction to domestic appliance noise (ii) to identify the noise index (or indices) that correlate highly with a subjective reaction to the noise, and (iii) to investigate the contribution of domestic appliance noise to an individual's daily noise dose. Two series of experimental studies were carried out using several examples of each of five types of domestic appliances. One determined the index values of domestic appliance noise - namely L_{WA} (using ISO 3741), L_{pA}, L_{pD}, L_p, PNL, $L_{Aeq,30sec}$, L_{Amax} and L_{AX}; the other determined subjective reactions to domestic appliance noise (judgements of noisiness, annoyance, the acceptability of the appliance noise and appraisals of usefulness). The success or failure of the research hypotheses was assessed statistically by analysis of variance, regression analysis, log linear analysis, Hotelling test, bootstrapping, *t*-test and post-hoc comparisons.

Ratings of annoyance, noisiness and the acceptability of the noise of the appliance were found to be interrelated and interdependent, and not influenced by appraisals of usefulness of the appliances. Noisiness ratings were the most consistent of the subjective ratings investigated, and were influenced by the duration of the exposure, and the actual appliance type under investigation.

Significant correlations were obtained between noisiness ratings and all the noise indices under investigation. However, statistical analysis demonstrated that L_{WA} correlated less successfully with noisiness ratings than all other indices. L_{Amax}, $L_{Aeq,30sec}$, and L_{AX} indices were the most successful. It is therefore suggested that the labelling of domestic appliance noise consist of L_{WA} and L_{Aeq} as measured in a standardised test environment. The percentage contribution of domestic appliance noise to the total daily noise dose of an individual was found to vary considerably depending on the sex and occupation of the individual. However, in terms of the daily personal noise exposure of an individual ($L_{EP,d}$) domestic appliance noise is insignificant.

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Chapter 1

Introduction

Every day, most adults in modern society use a domestic appliance, whether it is a kettle, vacuum cleaner, shaver or hair dryer. The noise these appliances emit, and the effect this has on the domestic noise environment, is something that is accepted; even though an appliance may be disliked because of its noise emission level, the labour saving value often outweighs all other feelings towards the appliance.

However, considering the extent to which domestic appliances feature in every day life, little is known about domestic appliance *noise*, other than a number of small studies to investigate the noise emitted by appliances *in situ*. Unlike other sources of noise, for example, aircraft, traffic and railway, there is little knowledge regarding the subjective reaction to domestic appliance noise. One may find the noise of a food mixer extremely annoying, but why? What aspects of the noise determine this annoyance reaction? Is it the low frequency content , the high frequency content or the overall noise level? If an appliance is declared as being noisy, on what grounds is this perception of noisiness made? What criteria determine whether the noise of an appliance is acceptable? Is there a relationship between an appraisal that an appliance is extremely useful, and the willingness to accept the noise?

Are there any other objective factors, beside tonal quality of the noise that determine a particular subjective reaction? Will a subjective reaction be identical, regardless of whether one is listening to the appliance or using it? Is there a relationship between the duration of exposure to the noise and a reaction to that noise?

Interest in domestic appliance noise was heightened, in December 1986, when the EEC issued a directive stating that all new appliances sold in Common Market countries, should be labelled with their A-weighted sound power level (if they are to be given a noise label). Throughout the discussion surrounding the directive, appeals were made by various consumer organisations that the choice of label should: (i) provide consumers with point of sale information about noise in order that this could help in their purchasing criteria and (ii) take into account subjective reactions to the noise.

There is limited knowledge, either objective or subjective, about domestic appliance noise. Consequently, the aims of this study were:

1. to evaluate the noise emission levels of domestic appliances

2. to investigate subjective reactions to domestic appliance noise

3. to determine how accurately the A-weighted sound power level index reflects these reactions

4. to identify a noise index that would reflect subjective reactions in the event that A-weighted sound power level was not suitable

5. to evaluate the extent of exposure to this noise source and identify the individuals most affected by it.

Chapter Two reviews the existing knowledge about domestic appliances. It begins with a discussion of various noise surveys of the domestic environment that have identified domestic appliances as significant noise producers. The research that followed can be classified into six categories: sound pressure level measurements of domestic appliances; sound power level measurements of domestic appliances; methods for noise control and reduction; the effect and amount of domestic noise exposure; noise labelling; and subjective reactions to domestic appliances. Each of these is discussed in turn.

To evaluate subjective reactions to domestic appliance noise, reference was made to the investigations regarding subjective reactions to other noise sources (such as aircraft, railway and traffic noise) in an attempt to define the components of people's reactions to noise - for example, loudness, noisiness and annoyance. **Chapter Three** presents these definitions and discusses the factors that have been identified as evoking subjective reactions to other noise sources. The remainder of Chapter Three describes the subjective measuring techniques to be used and the factors to be investigated in the present study, based on a review of the literature relating to subjective reactions to other noise sources.

Chapter Four discusses the hypotheses that were investigated during the research project, as identified in Chapter Three. They consider a number of factors that could influence a particular subjective reaction to domestic appliance noise. For example: Is a subjective reaction determined by the length of time the appliance is in use? Does the perceived usefulness of an appliance affect the noise rating given? If the subject becomes highly annoyed by the noise, will this also affect the rating given? Is the noise rating dependent on whether the subject is using the appliance or simply listening to it?

To examine these hypotheses, two types of experimental studies were carried out. In **Chapter Five** experiments to determine the *objective* quantities of domestic appliance noise such as A-weighted sound power level (measured according to ISO 3741 - Acoustics - Determination of Sound Power Level of Noise Sources - Precision methods for broad band sources in reverberation rooms.), A-weighted, D-weighted and linear sound pressure level, Perceived Noise Level, equivalent continuous A-weighted sound pressure level, maximum A-weighted sound pressure level and single event noise exposure level are discussed. Measurements were made on hair dryers, food processors, food mixers, liquidisers and vacuum cleaners.

Experiments to determine the *subjective* reactions to domestic appliance noise are described in **Chapter Six**. The experiments were based on a balanced Latin square design. The justification for the choice of this design is discussed, along with details regarding choice of subjects, questionnaire construction, and the experimental room used.

Before presenting the results obtained during the experimental studies, **Chapter Seven** describes the statistical techniques used to analyse the data generated and the justification for the techniques chosen. Analysis of variance and regression analysis were among the techniques used. The results of the analysis of data for each research hypothesis are presented in **Chapter Eight**, along with a summary of the main findings.

An investigation into the contribution of domestic appliance noise to an individual's 24 hour noise dose is described in **Chapter Nine**. The main conclusions to be drawn from the study and suggestions for further work are described in **Chapter Ten**.

Chapter 2

Literature Review

2.1 Surveys of the Domestic Noise Environment

There has been interest regarding the noise levels prevailing in the domestic environment for many years. One of the earliest studies considering such noise levels was that undertaken for the Building Research Station in 1948 [1]. The object of the study was to obtain information regarding the incidence of complaints of noise in houses and flats in order to guide the direction of future experimental work undertaken at the Building Research Station. The sounds originating in the home, which were noticed, included: "Wireless in other rooms", "Cistern of the water closet or the hot water cistern" and "doors banging". With the exception of the wireless, there was no specific reference to domestic appliances, possibly because many of the more common appliances now in use were not readily available to the average householder in the years following the Second World War.

Following the publication of this report, interest was largely directed towards investigations of noise levels encountered by people in their working environment and from other sources. However in 1958, research focused attention once again on noise levels in the domestic environment with reference to the items inside the home that contribute to the overall noise level [2]. The kitchen was identified as a potential high noise level area, where electrical appliances such as waste disposal units, dishwashers and food mixers are in use. Vacuum cleaners were identified as generators of significant noise levels, and a general conclusion was that these machines would remain noisy unless they were made quieter by manufacturing re-design. (Discussion of the reduction of noise by design is outside the scope of this thesis.) Table 2.1 shows the levels of noise emitted by some appliances in 1958.

Table 2.1 Noise level emissions of a number of commonly used appliances, in the 1950s [2].

Appliance	L_{pA}
Food Mixer	76
Vacuum Cleaner	74
Dishwasher	70
Tumble Drier	64
Floor Fan Heater	63
Extractor Fan	75

In 1961 an investigation was made [3] whose purpose was to consider in more detail the noises that arise within the home and to consider ways of reducing the noise. It was noted that the use of domestic appliances was increasing and included refrigerators, washing machines and spin dryers, tumble dryers and dishwashers, vacuum cleaners and floor polishers and electric tools for the home workshop, appliances familiar in homes today.

Two years later, in 1963, an extensive study on noise was undertaken by the Committee on the Problem of Noise [4], whose aims were:

> ....to examine the nature, sources and effects of the problem of noise and to advise what further measures can be taken to mitigate it.

The investigation included a study of noise within dwellings and a survey of attitudes to noise. The survey revealed that people were more concerned by noise when they were at home indoors than when they were outside. Listed among the sources of noise which disturbed people at home were domestic/light appliances and radio/television. The committee commented that the services and equipment people expected in their homes were potential sources of extra noise, and contributors to this noise included labour-saving domestic equipment, radio, television, record players and tape recorders. The need for quieter domestic appliances such as vacuum cleaners and washing machines was also noted by women's organisations e.g. Women's Institute, who gave evidence.

Recently research concerned with noise in the domestic environment, has focused on the incidence of complaint against noise from domestic premises. In one study, [5] it was reported that domestic appliances such as television, radio, Hi-Fi, washing machines, spin-dryers and vacuum cleaners have become sources of potential noise complaint especially in multi-occupancy dwellings. In another study, [6] of complaints about noise from domestic premises, included among the minor sources of complaint mentioned were domestic appliances. However, it must be emphasized that in general, domestic appliances are not usually a cause of disturbance for neighbours, but for the user of the appliance, and listeners within the same dwelling.

With the emergence of a general awareness about noise in the domestic environment and the identification of domestic appliances as generators of significant noise levels, subsequent activities concerning domestic appliances may be listed as follows:

1. measuring the sound pressure level (L_{pA}) of domestic appliances either *in situ* or in specially constructed domestic rooms;
2. measuring the sound power level (L_{WA}) of domestic appliances;
3. investigating the methods of noise control of domestic appliances;
4. investigating the effect and amount of domestic appliance noise exposure;
5. considering methods of labelling domestic appliances with their noise emission levels;
6. considering the subjective reaction to domestic appliance noise.

Each of these activities will be discussed in turn.

2.2 Sound pressure level measurements (L_{pA}) of domestic appliances

One of the most frequently quoted studies of domestic appliance noise was that published by the United States Environmental Protection Agency (EPA) [7]. Domestic appliances were identified as constituting an increasing noise problem within the home, and it was concluded that, without exception, the noise could be significantly reduced.

At the time of the report, the EPA noted a scarcity of reliable data concerning A-weighted sound pressure levels of domestic appliances. Therefore they made measurements, at a distance of approximately 1m and a height of approximately 1.5m from thirty types of appliances, representing the levels at the location of the operator's ear (or the sound pressure level in the vicinity of those appliances not requiring an operator). Table 2.2 shows the range of results obtained for the more commonly used appliances.

Table 2.2 Range of A-weighted sound pressure levels for a variety of domestic appliances [7].

Appliance	Range (L_{pA})	Average (L_{pA})
Freezer	39-45	41
Refrigerator	35-52	42
Heater-electric		47
Fan	38-69	58
Tumble Dryer	51-66	59
Electric Shaver	47-69	60
Hair Dryer	59-65	61
Washing Machine	48-72	62
Dishwasher	54-72	65
Food Mixer	49-79	67
Vacuum Cleaner	62-85	72
Liquidiser	62-88	75

From Table 2.2 it is evident that the noisiest appliances were among the appliances normally located in the kitchen - namely liquidisers, food mixers, dishwashers and washing machines, although the noisiest vacuum cleaners produce similar noise levels.

Research in Britain also provided a significant contribution to the awareness of domestic appliance noise. Jackson and Leventhall [8] investigated the A-weighted sound pressure levels of eighteen commonly used appliances, studying up to ten models of each type. Appliances were excluded where the operator could control the noise output level. Measurements were taken in acoustically-simulated average domestic rooms and *in situ*. Appliances were divided into three main groups: kitchen appliances; living room and bedroom appliances and bathroom appliances. For the kitchen appliances requiring a load (for simulation of normal use conditions), a mixture of bread crumb and water slurry was used (this being a substance whose volume or consistency does not change).

In this study, it was also noted that the kitchen was the most noisy room in the house. Appliances investigated included food mixers, liquidisers, washing machines, spin dryers, hot-air tumble dryers, dishwashers, extractor fans, water heaters and gas cookers. The A-weighted sound pressure levels emitted by living room appliances were more modest, ranging from 35 to 50 dBA, and included electric fans and gas fires. Bedroom appliances consisted of vacuum cleaners and alarm clocks. The average A-weighted sound pressure level of vacuum cleaners was 76 dBA, which was considered "excessively high". Appliances used in the bathroom included hair dryers (average level of 70 dBA), electric razors (average 80 dBA), electric tooth brush and toilets. Table 2.3 shows the A-weighted sound pressure levels for the electrical appliances most commonly used.

It will be noted that the range of levels obtained are very similar to those obtained by EPA (however, it should be emphasized that it is difficult to compare A-weighted sound pressure levels as they are dependent on the environment in which the measurements are made). Of all the appliances investigated, the values for hair dryers seem to have changed the most, with the highest value recorded by EPA being only slightly higher than the lowest value recorded in the British study.

It was concluded from this study [9] that housewives were exposed to

Table 2.3 Range of typical domestic appliance noise levels [8].

Appliance	Range (L_{pA})	Average (L_{pA})
Fan Heater	37.2 - 53.4	47.3
Tumble Dryer		62.6
Electric Shaver	64.4 - 83.4	73.7
Hair Dryer	63.2 - 79.0	70.4
Washing Machine	54.0 - 77.6	69.4
Dishwasher		70.6
Food Mixer	58.6 - 85.2	71.8
Vacuum Cleaner	67.0 - 82.8	76.5
Liquidiser	57.4 - 89.6	75.6

levels of noise during part of their day that approximated an industrial environment (although no indication was given about the actual level referred to). Also there was a tendency to smaller, cheaper appliances which contributed to increasing the levels of noise to which housewives were exposed.

The interest in the measurement of A-weighted sound pressure levels of domestic appliances has continued and is a popular topic for students studying for the U.K. Institute of Acoustics Diploma in Acoustics and Noise Control. Two recent reports have undertaken such an investigation. In one report [10] six domestic appliances were investigated: washing machine, vacuum cleaner, liquidiser, food mincer, food mixer, and electric shaver. Measurements were taken at the operator position, within the same room as the appliance and within an adjoining room (with the interconnecting door closed). The results are presented in Table 2.4. Levels recorded for the food mincer at the operator position seem excessively high, and would make it impossible to hold a conversation in the same room. Even in an adjoining room, the level remains high.

In the second report [11] a study of domestic appliance noise levels was made and the results compared with those obtained in 1975 [8]. The appliances under investigation were similar to those in the 1975 study and (when required) the load conditions were identical. Table 2.5 shows the results obtained for the more commonly used electric appliances.

Table 2.4 Domestic appliance noise levels and noise levels in the same room and an adjoining room [10].

Appliance	Operator (L_{pA})	Room (L_{pA})	Adjoining Room (L_{pA})
Electric Shaver	74	59	42
Washing Machine		75	54
Food Mixer	82	75	49
Vacuum Cleaner	83	80	54
Liquidiser	84	80	61
Food Mincer	92	89	65

Table 2.5 Comparison of Domestic appliance noise levels in 1984 and 1975 [11].

	1984		1975	
Appliance	Range (L_{pA})	Average (L_{pA})	Range (L_{pA})	Average (L_{pA})
Tumble Dryer				62.6
Electric Shaver	59-80	69.7	64.4-83.4	73.7
Hair Dryer	64-82	73.9	63.2-79.0	70.4
Washing Machine	52-69	63.5	54.0-77.6	67.4
Food Mixer	64.5-86.0	74.7	58.6-85.2	71.8
Vacuum Cleaner	67.5-84.0	76.3	67.0-82.8	76.5
Liquidiser	59.0-85.0	75.0	87.2-89.6	88.6

It was concluded that, with the exception of the average liquidiser levels, there is little evidence of noise reduction since the 1975 study.

2.3 Sound power level measurements (L_{WA}) of domestic appliances

Because the sound pressure level of an appliance represents the level occurring at one particular time and in one particular location, some researchers concentrated on using a more definitive measure of the noise level produced by a domestic appliance. They investigated the methods of obtaining the sound power level of domestic appliances. The problem associated with the sound pressure level measurements is that they vary considerably with distance and angular position. Therefore a single point measurement is not sufficient to represent completely the noise produced by a machine, and it is necessary to make measurements which represent the entire noise output of the machine. The parameter which would appear to be most useful is the level of the total acoustic power. The sound power level gives the total sound power radiated by the appliance in all directions and is usually measured in one-third octave, octaves or as A-weighted [12].

The measurements can be made either in an anechoic chamber or reverberation chamber. (For more details see Chapter 5, section 5.1). The following discussion will concentrate on sound power level measurements specifically related to domestic appliances, and the problems encountered obtaining these measurements.

2.3.1 Choice of test environment

The choice of test environment (anechoic or reverberant) has been a topic for discussion for a number of researchers. Roewer [13] identified the unsatisfactory and confusing position regarding which type of test environment to use. Nine distinct environments were noted, which ranged from test rooms with hard walls to outdoor spaces.

The choice is to some extent determined by the appliance under investigation. When considering a method for determining sound power level values for domestic gas appliances [14], the following arguments were considered. The anechoic test room would provide sound power level values and also directivity information for an appliance. The reverberation test room provides only sound power level information. The anechoic room requires more complicated measurements, but the directivity characteristics of gas appliances would be neglected using a reverberation room. The solution to this dilemma was to design a test room to have the same acoustic environment as an average domestic room.

The choice of test environment for other researchers [15] was an isolated anechoic room, because some of the appliances investigated emitted noise levels down to 25 dBA. Use of an isolated anechoic room meant that reliable measurements could be obtained down to 18 dBA (the ambient noise level of the chamber).

The accuracy of the measurements obtained using the anechoic and reverberant test environments was questioned by Dr. P V Bruel [16] who was concerned with systematic differences between reverberant and free field determinations of sound power levels. His interest lay in International Standards 3741 and 3742 [17] [18] which describe methods where the sound power is determined from measurements of sound pressure levels and reverberation time of the reverberation room; and International Standards 3744 and 3745 [19] [20] which describe methods of measurement in an anechoic chamber where the sound pressure is measured over a hypothetical hemisphere enveloping the machine under test. The problem with the two measurement methods is that the sound power level determined in a reverberation room is always lower than that determined in an anechoic chamber. This is significant at low frequencies. To overcome this problem, Bruel suggested the comparison method, whereby the sound pressure level of a reference sound source of known sound power output is measured in a reverberation room, and compared with sound pressure level of the appliance under test, provided they are both placed in the same position in the room.

2.3.2 Positioning/Location of appliances during measurements

All types of appliance should be tested without an operator and in a position or location approximately as close as possible to normal use. The following positions are recommended [13]:

1. In all cases a hard floor is required.
2. Hand-held appliances should be resiliently suspended.
3. Table type appliances should be placed on a standard table.
4. Appliances for use on the floor should be placed on a piece of floor covering, far from walls.
5. Appliances used against a wall should be placed within a distance of 0.1m from a hard reflecting wall.
6. Wall mounted appliances should be mounted as in normal use.

2.3.3 Precautions

During their research Harrison, Melling and Konowicz [15] identified the following problems when measuring the sound power levels of domestic appliances:

1. Appliance noise can have strongly directional characteristics.
2. Some appliance noise levels may vary during operation - for example washing machines and spin dryers.
3. For such appliances of cyclical nature, measurements must be taken for each part of the cycle.
4. The noise level of appliances can change over long periods of use.

These factors must be considered during measurements with domestic appliances.

2.3.4 EEC Directive

In 1986, the EEC [21] finalised its directive on noise emitted by domestic appliances referring specifically to the sound power level measurement method as directed in the International Standard IEC 704-1 (1982) [22]. This standard applies to electrical appliances for household use, that are supplied from mains or batteries. The measurement method is either the direct method or the comparison method. The direct method can be used only for measurements in qualified environments according to ISO 3744 [19] and ISO 3743 [23]. Details of the comparison method are also found in these standards. (For an explanation of the terms 'direct' and 'comparison' see Chapter 5, section 5.1.1). The test code covers all aspects of the measurement procedure, including operation and loading of the appliances under test.

2.3.5 Choice of measurement method

In general, when carrying out sound power level measurements on domestic appliances, the choice of a particular method is usually guided by the following factors:

- the size of the noise source
- the test environment available, whether it is an anechoic or reverberation room. If a reverberation room is used, then the use of a reference sound source minimizes many of the problems encountered when using such a room.
- the character of the noise produced by the source, taking note that some noise levels may vary during operation and certain appliances exhibit strong directional characteristics of noise emission.
- the highest grade of accuracy required, whether it is precision, engineering or survey accuracy.

- the acoustical data needed to fulfill the purposes of the measurement (whether only sound power level measurements are required, or directionality measurements also.)

2.4 Noise control of domestic appliances.

Some researchers have concentrated on identifying the parts of the appliance generating the noise, with the ultimate aim of noise reduction. Certain components of the noise may be more disturbing than the overall noise level itself, and if these can be identified, they could be removed or reduced. Although discussion of the methods of appliance noise reduction are beyond the scope of this study, it is important to identify noise generating components, as this information may help explain unusual subjective reactions to certain domestic appliances.

In the vast majority of domestic appliances there is an electric motor to drive the machine, and in an investigation into the sources of noise from small electric machines [24] it was found they were from three sources:

Mechanical: - this produces vibration directly in the machine structure and could be caused by out-of-balance conditions of the motor, producing low frequency noise, resulting in structure-borne vibration.

Magnetic: - this is caused by air pressure fluctuations in the space between the rotor and stator due to the magnetic flux. The largest displacement of waves and the loudest noises will be produced when forcing frequencies are equal to or close to the natural frequencies of the structure, causing resonance.

Aerodynamic: - this noise occurs when there is any rapid local change in the pressure of the ventilating air flowing through a machine.

The frequency spectrum of the resulting noise is usually of the broad-band type with superimposed pure tones, some of which may be harmonics.

A number of researchers have considered the noise control of domestic appliances in general ([25], [26], [27]). Other researchers have chosen specific appliances for in-depth investigations into the sources of noise and noise control. In one study [28] three sources of noise were identified from spectral analysis of a vacuum cleaner. These were:

1. a nearly pure tone in the one-third octave band centered at 315Hz caused by the vibration of the motor fan unit.

2. a nearly pure tone in the one-third octave band centered at 2000Hz caused by the interaction between fan blades and stators.

3. a broad band noise between 600-3000Hz caused by the turbulent air flow in the motor-fan unit.

For the liquidiser ("food blender") the source of noise is the motor, the air movement noise, structure borne noise and agitating noise of the load [7]. The sources of noise of hair dryers are the motor, the fan, and airflow. A faster drying rate is achieved by greater air flow and higher temperatures, but this increases noise from the fan. For the vacuum cleaner, the primary sources of noise were identified as being the motor, blower, resonances of the unit structure and, in upright vacuum cleaners, the mechanism beating the carpet.

In summarising the noise sources of domestic appliances, it can be concluded that the major sources of noise are similar for many domestic appliances:

- Motor noise, which is, in general, low frequency (around 315 Hz) and tonal in character.

- Air movement noise, which is high frequency noise and present in the spectra of extractor fans, vacuum cleaners, fan heaters, hair dryers and food mixers.

- Mechanical vibration, resulting from the movement of the component parts of the appliance, which is often intermittent.

The combination of these sources of noise give a broad band spectra with pure tones superimposed.

2.5 The amount and effect of domestic appliance noise exposure.

Very little published data has been found on the amount and effect of domestic appliance noise exposure. An investigation was made, for EPA [7], of the extent of exposure to household appliances whose volume could not be controlled by the operator. The distribution of appliances among families was considered, along with the length of typical operation of the appliance and the number of people exposed to the noise in the home. Appliances were classified into three groups:

1. Quiet major appliances, characterised by A-weighted sound pressure levels less than 60 dBA.
2. Small appliances characterised by A-weighted sound pressure levels between 60 and 70 dBA.
3. Noisy small appliances characterised by A-weighted sound pressure levels between 70 and 80 dBA.

Group 1 appliances included fans, air conditioners, tumble dryers, humidifiers, freezers and refrigerators. These appliances were found to be in widespread use and comprise the noise sources to which people are exposed for the greatest length of time in the home. The main effect to people exposed to such noises was mild and consisted of possible speech interference in the vicinity of the appliance.

Group 2 appliances included plumbing (taps and toilets), dishwashers, vacuum cleaners, food mixers, washing machines, electric can openers, hair dryers and electric knives. These appliances were found to be in widespread use, although not as common as those in Group 1. Exposures were usually brief and infrequent. The major effect of exposure to their noise was found to be speech interference and interruption of conversation.

Group 3 appliances consisted of electric shavers, liquidisers, waste disposal units and lawn mowers. Such appliances were found to be less widely used than Group 2. The major effect of noise exposure from these appliances is severe speech interference and annoyance due to possible pure tone components and the variable distribution of sound levels, typical of this group.

It is not possible, however, using this information, to determine the percentage of energy contributed by domestic appliances, to an individual's 24 hour noise dose, information which is essential in considering domestic appliance noise as a potential noise nuisance. This information is discussed in Chapter 9

2.6 Noise labelling of domestic appliances.

The need for labelling domestic appliances with their noise level was suggested over twenty five years ago [3], when it was reported that the noise emission level was something the purchaser needed to bear in mind when purchasing appliances, as there were no standards for quietness of operation of these appliances. The only guide at the time to the potential noise performance of an appliance was the loudness ratings given to new appliances by Consumer's Association Ltd. The ratings were of a verbal nature, for example, 'loud' or 'moderately loud', with no definition of the noise level in terms of decibels. Two years later, in another study [4] it was suggested that domestic appliances should be labelled to enable customers to compare the noisiness of different models of appliances.

Another investigation recommended labelling appliances that generated significant noise levels, that would primarily affect the user [7]. Labelling was preferred, rather than standard setting, so that a person could be informed of the noise to which s/he would be exposed, and then be free to consider noise as but one of a number of factors accounting for the selection of a particular appliance. Noise control standards would only result in a rise of appliance prices which would unnecessarily restrict the consumer's range of choice. There was no suggestion as to the possible format of the label and the information it should contain.

The need for developing a noise labelling system was also stressed by P K Baade [29]. He suggested that the data obtained about an appliance's noise emission level should be processed into the simplest form possible which would take into account the subjective reactions of people. No possible format was suggested.

Concern was voiced about how to express the noise rating system of domestic appliances so that it would provide "informative labelling".[13] At the time of this paper (1973) a new ANSI Draft Standard for household appliances had proposed that the index for product noise rating should be *A-weighted sound pressure level* at specific distance of 1m from the appliance. However, acoustic experts in Europe preferred to use *A-weighted sound power level.*

In order to standardise the procedure the EEC Directive [21] aimed to ensure that the noise labelling of domestic appliances conformed to a number of agreed principles. The proposal for the directive arose out of the stated French intention to introduce an enforceable noise labelling scheme in their country. If enacted, it was felt that this could result in a barrier to trade. They were therefore persuaded to join discussions on an EEC Directive and postpone their own legislation. There were two other reasons for suggesting a labelling scheme:

- on environmental grounds - to reduce the general level of noise to which people are subjected
- to provide consumers with point-of-sale information about noise in order that this could help in buying decisions, possibly make them more aware of noise and eventually lead to a demand for quieter appliances.

After many years of discussions the EEC Directive was finalised in December 1986. It called for the noise labelling of new domestic appliances, using A-weighted sound power level. To determine the A-weighted sound power level of an appliance the guidelines as laid down in IEC 704-1 [22] should be followed. The proposal does not require member states to introduce the noise labelling of domestic appliances as a statutory requirement.

Member states wishing to make such labelling mandatory may do so provided the methods prescribed in the directive are followed. (The British Government are not making labelling mandatory, and are not requesting information about noise emissions for the label [30]).

Having decided upon the format of the label, one study assessed how the actual value quoted would be determined [31]. Three statistically different methods of arriving at a given value were identified. The first was to use the mean value from a series of tests of the noise emission level of a particular appliance type. However it was felt that this value would not be informative for a customer only buying a single item. With a standard deviation of 2 dB for a series of appliances, a single item can possess a higher or lower value than the mean - in fact up to three standard deviations or 6 dB from the mean value. Something more informative to the customer would be an absolute maximum value, which would guarantee that no single item of a series produced more noise than the labelled value. This system would not be popular with manufacturers who would have to adopt a labelled value which was considerably higher than the mean value for the series.

The third option would be to chose a label with a statistical maximum value, this being the value for which 10% of all the series investigated are allowed a noise value above this labelled value - for a series with a standard deviation of 2 dB, this approximates 2.5 dB above the mean value. It was concluded that the statistical maximum value provided better information to the customer than the mean or absolute maximum value.

2.7 Subjective reaction to domestic appliance noise.

There has been a considerable amount of research investigating subjective reactions to various other noises (see Chapter 3) but very limited research investigating reactions specifically to domestic appliance noise. (A detailed discussion of the methodology adopted in these studies will be discussed in Chapter 3, section 3.4). In one study [29] a very simple investigation of the subjective reactions to domestic appliance noise was carried out by asking one subject to judge the noise levels of a variety of appliances in the home. It was accepted that different people react to the same noises in a different way, and a specific person would accept a much higher noise from one appliance than for another. In the tests, there was 20 dB between the loudest and quietest appliance but the subject judged them all about equally acceptable. The highest noise level was emitted by the dishwasher, but the appliance was deemed acceptable because of its labour-saving advantage. Its location in the kitchen meant it did not interfere with activities in other locations throughout the house. The air conditioner emitted noise levels less than the dishwasher, but they were certainly audible. However acceptability was linked to necessity - it was only used when there was a need for cool air, which outweighed a need for quiet.

This simple test highlighted some of the factors potentially involved in a subjective assessment of domestic appliance noise - namely acceptability of the noise level was determined by the labour-saving nature of the appliance and the general usefulness it provided which could outweigh any noise level emissions.

In an investigation of the problems of measuring and assessing electrical appliance noise [15], a further small scale study of the subjective assessment of domestic appliance noise was made. Several laboratory staff, of all ages, male and female, were invited to listen to some appliances under test in an anechoic room and to rate the noises as "noisy", "normal" and "quiet". It was acknowledged that the panel was small (three people) and that the results would be conditioned by various factors:

1. by the degree of noise expected from an appliance related to the room in which it would normally be used.

2. by the activities in which the subject was involved prior to the test taking place.

3. by the change of panel members which was inevitable over an extended period.

4. by the use of only three classes of assessment.

Perhaps the most interesting finding of the study was that the rating given for a particular appliance seemed to be dependent to some extent on whether the subject was a user or non-user of the appliance. It is unclear from the research paper, however, whether 'user and non-user' refers to the subject owning such an appliance in his/her own home, or whether measurements were made with a subject operating the appliance and giving ratings under these conditions. It was found that for the user a high level (60-80 dBA) was acceptable, but for the non-user a similar level was found objectionable. This finding warrants further investigation.

Researchers at the Institute of Sound and Vibration Research at Southampton University have investigated the noise level index that correlates most with subjective reactions to various domestic appliances. In one study [32], the predictive abilities of sound level in dBA, dBB, dBC, equivalent continuous A-weighted sound pressure level and PNL were investigated. Preliminary tests were conducted to validate the use of recorded stimuli, using twenty subjects who rated five pairs of domestic appliance types, in live and recorded mode. As no significant differences were found between ratings, recorded stimuli were used in subsequent tests. Twenty five subjects were required to rate the noise level of one of each type of appliance at five different levels, using a balanced Latin square design (see Chapter 6, section 6.5) to determine order of presentation. Using the category scaling technique (with a scale range of 0-9) subjects rated noises according to judgements of noisiness. The results were analysed using analysis of variance. The PNL scale provided the highest correlation (0.978) but this was not found to be significantly different from that obtained for dBA. The possibility of using A-weighted sound power level as an index was not investigated in this study.

Another study [33] examined the variability in subjective reaction that occurred when subjects were exposed to various noises from two appliance types: fan heaters (chosen for the constant noise emission level) and washing machines (chosen for the cyclical nature of the noise). As in the previous study, the mean subjective response was examined in terms of various noise indices. Again, high correlations were obtained between ratings and a number of the indices. Regression analysis was conducted to determine the nature of the relationship between ratings and indices. In the case of the fan heater experiments it was concluded that the experimental method was not appropriate and the regression lines were not meaningful. High correlations were obtained for dBA, dBB, dBC and dBD for the washing machines. It was suggested that two numbers on a label would best represent washing machine noise - one for the wash cycle and one for the spin cycle - the dual numbering would be of more use to the purchaser than a single number. No investigation was made of A-weighted sound power level as a noise index in this study.

From examination of these studies, a number of issues that warrant further investigation were suggested:

- acceptability of the noise level of an appliance was determined by the labour-saving nature of the appliance, and the general usefulness it provided could outweigh any noise level emissions.
- ratings of noisiness for a particular appliance seemed to be dependent on whether the subject was a user or non-user of the appliance.

None of the studies investigated the factors evoking subjective responses to domestic appliance noise. They concentrated only on one response, namely perceived noisiness, and the possibility of using A-weighted sound power level as a noise index was not investigated.

2.8 Summary

1. Concern about noise in the domestic environment is not new, and surveys over the past thirty years have identified domestic appliances as potential sources of noise nuisance and complaint.
2. A number of studies have measured A-weighted sound pressure levels of domestic appliances. (No study specifically measured the A weighted sound power levels of appliances - the studies discussed in section 2.3 concentrated on the measurement techniques). The kitchen

was identified as the noisiest room in the home, with appliances such as liquidisers, emitting noise levels in excess of 80 dBA. Noise levels from appliances have not decreased significantly over the last twenty five years.

3. The choice of method for measuring A-weighted sound power levels of domestic appliances is determined by a number of factors such as the test environment available, the highest grade of accuracy required, and the acoustic data needed to fulfill the purposes of the measurement. Care should be exercised when making such measurements, as the noise emission level of domestic appliances can change over long periods of use.

4. Various studies have identified the major sources of domestic appliance noise, which are identical for most appliances. These are: motor noise (usually low frequency and tonal); air movement noise (usually high frequency); and noise resulting from mechanical vibration. The combination of these sources of noise give a broad band spectra with pure tones superimposed.

5. Appliances emitting the highest A-weighted sound pressure levels and causing the severest effects on individuals in the vicinity (usually speech interference) are not those appliances to which noise exposure is greatest.

6. The need for a domestic appliance noise label is not new, but until 1986 few researchers suggested a format for the label. They merely indicated that the label should be informative and take account of subjective reactions. With the finalising of the EEC Directive in 1986, the format of the label was to be A-weighted sound power level, measured according to guidelines laid down in IEC704-1.

7. Assessment of the subjective reaction to domestic appliance noise is severely limited and has concentrated largely on judgements of noisiness, correlated with a number of noise indices, with the exception of

A-weighted sound power level.

2.9 Conclusions

From an examination of the literature referring to domestic appliance noise, there are clearly a number of areas where the knowledge is severely limited, and where further research is required:

1. A comprehensive study is needed to assess the factors that are involved in a subjective assessment of domestic appliance noise. It is necessary to examine a number of subjective reactions, and not just concentrate on one, such as noisiness or annoyance. Thus all the components of subjective reaction can be distinguished and not just one component part of that reaction.

2. The 'objective' components of the noise that influence a particular subjective reaction must be identified. Will aspects of domestic appliance noise produce similar reactions as, say, aircraft noise, where the high frequency noise content is regarded as particularly annoying? Will subjective ratings vary depending on whether the subject is using the appliance or listening to it? What will be the effect of elongation of exposure to domestic appliance noise? These issues have not previously been examined for domestic appliance noise.

3. In the light of the EEC Directive related to household appliance noise, it is necessary to determine how well the A-weighted sound power level index correlates with subjective reactions. This necessitates making A-weighted sound power level measurements for a number of appliances, according to one of the recommended methods and correlating these values with subjective ratings to the same appliance noise.

4. In addition to assessing the suitability of A-weighted sound power level for the acoustic labelling of domestic appliances, it is important to assess the suitability of a number of other noise indices (as in previous

research), and determine how well they correlate with subjective ratings of the same appliance noise.

5. An investigation is required to determine the contribution by domestic appliance noise to an individual's 24 hour noise exposure level and to relate this to occupational noise exposure level e.g. 8hour L_{Aeq} of 90 dBA.

The research discussed in this thesis aims to investigate these areas, and thus enable an assessment of domestic appliance noise to be made.

Chapter 3

Assessment of Subjective Reactions to Noise

Research has demonstrated that there are considerable differences between people's reactions to noise. Considering the complexity of variables contributing towards a subjective reaction, the usefulness of investigating subjective reactions to noise is questionable. However, this type of investigation is considered important by some researchers [34] because when developing standards, for example, for urban areas, the lack of a clear understanding of the factors affecting people's response to noise hinders the setting and maintenance of standards. Therefore researchers have tried to establish the relationship between a subjective rating of noise (as measured on attitude scales), and objective measurements (made with a sound level meter) to evaluate the sound level corresponding to points on the subjective rating scales as judged by the average listener.

As a principal part of the present research it was necessary to identify the factors contributing towards a subjective response to domestic appliance noise and to ensure that these factors are considered when deciding upon the appropriate method of labelling the sound output of a domestic appliance.

This chapter aims to examine the subjective reaction to noises in terms of:

- defining a number of commonly used terms to describe subjective perceptions of noise - namely loudness, noisiness and annoyance.

- discussing the factors eliciting such perceptions
- describing measures used to quantify these perceptions
- examining the methods adopted by researchers in their attempts to measure subjective reactions to noise.

3.1 Definitions of loudness, noisiness and annoyance

It is well established that the subjective reaction to sound is a very complex one [35].

Figure 3.1 represents the curves for equal loudness of pure tones. These curves were obtained by asking a panel of subjects to equate the loudness of pure tones at each frequency, to a pure tone at 1kHz. It can be seen that the ear is less sensitive to low frequencies and very high frequencies over the range 0.02 - 16kHz. Also, it will be noticed that a change of frequency sensitivity occurs with intensity. The contours become more level as intensity increases. Although these relate to pure tones only, they do demonstrate that subjective reaction to sound depends on both frequency and intensity.

The subjective experience with sound can be conceptualised along a number of different dimensions which vary in the extent to which they emphasize feelings and the emotional aspects of the reaction to noise. Research has revealed that three components of people's reactions to sound can be distinguished:

loudness: this represents a judgement of the strength of a sound [36]. It is the subjective assessment of the magnitude of a sound and it differs from noisiness or annoyance, which are defined below. Berglund [37] defines loudness for a panel of subjects as the perceptual aspect of the noise that is changed by turning the volume knob on a playing radio set.

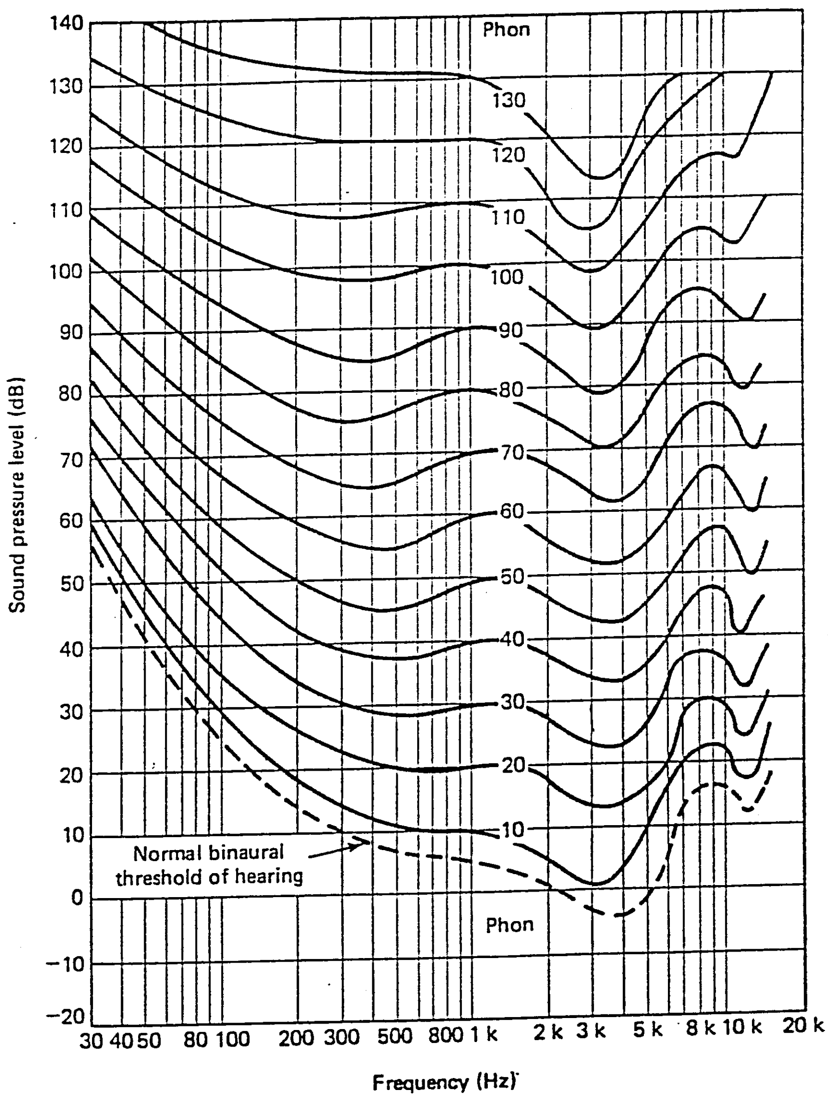


Figure 3.1 Curves of Equal Loudness.

noisiness: this is defined by Kryter as the degree of unwantedness of a not unexpected, non-pain or fear-producing sound as part of ones environment [38]. It is also known as 'perceived noisiness', and thus encompasses terms such as 'unwantedness', 'unacceptableness' and 'disturbing'. Henceforth in this thesis, it is simply referred to as *noisiness*. According to May [39] noisiness and loudness are best evaluated in a laboratory by psychoacoustical experiments. Research [37], [40] showed that listeners judged the noisiness and loudness of a series of airplane and community noises to be significantly different from each other.

annoyance: this is defined by Borsky [41] as being the feeling of displeasure associated with any agent or condition believed by an individual or group to be adversely affecting them. A person's annoyance will include his or her assessment of the unwantedness of the sound itself (its noisiness) plus many other non-acoustic variables which depend on the source of the sound and the context in which it is experienced, and which can make a sound of a given noisiness induce different levels of annoyance.

Research has shown [42] that it is possible to distinguish between ratings of loudness, noisiness and annoyance. In the laboratory study subjects experienced aircraft noise as more annoying than noisy and more noisy than loud. According to Preis [43] (and as demonstrated in the overlap of the above definitions) there are reservations about the distinction between annoyance and noisiness. One researcher comments that in order to predict the annoyance response of a community, one must consider both the response to the physical characteristics of the exposure and psycho-social variables [44]. In [45] it is claimed that it is possible to define noisiness as a 'judgement' and annoyance as an 'attitude'.

3.1.1 Summary of subjective rating terms

Subjective reaction to sound is very complex and research has revealed three components of subjective reactions: loudness, noisiness and annoyance. Although these components can be defined and examined separately, there is a degree of overlap between annoyance and noisiness such that a perception of annoyance includes an evaluation of noisiness.

3.2 Factors evoking a subjective reaction to a noise source

There are several acoustic and non-acoustic factors that contribute towards evoking a subjective reaction to a noise source in individuals. These have been identified through the study of subjective reactions to various noise sources.

3.2.1 The physical characteristics of the noise itself

The following acoustic properties have been identified as responsible for evoking feelings of annoyance, the willingness to complain and perceptions of noisiness in individuals:

1. The intensity of the noise. [46] [42] [47] [38] [48]
2. The frequency content (particularly if pure tones are present). [42] [43] [48] [49] [47] [46]
3. The duration of the stimulus. [42] [38] [46]
4. Whether the noise is cyclic, intermittent or steady state. [42] [48] [49]
5. Whether the noise is impulsive. [48]
6. Whether the noise has a rapid rise time. [49] [46]

Linked to these factors are:

1. The number of noise events. [50]

2. The level of ambient noise prevailing at the time. [50]

3.2.2 Situational, Cognitive and Social Factors

Along with factors relating to the acoustic properties of a noise source, the following factors have been identified as related to feelings of annoyance and willingness to complain about noise:

1. Social awareness to noise in general. [51]
2. The characteristics of the individual especially personal sensitivity to noise in general. [51] [50] [48]
3. The time of day when the noise occurs. [39] [42]
4. Whether the noise resembles another already disliked and which perhaps threatens danger. [42] [39] [48]
5. Whether the noise could have been avoided. [39] [42] [50] [48]
6. Whether the noise source is visible. [39]
7. Whether the noise is new. [39]
8. The activity with which the noise interferes e.g. sleep, speech, watching TV, relaxing. [42] [48] [46]
9. Whether the noise contains information e.g. speech, music. [48] [46]
10. Whether the product of the noise is useful or personally valued. [42]
11. Whether the noise is believed by the subjects to affect their health. [50]
12. Whether the subject feels s/he has feelings of control over the noise. [52]
13. Whether the subject is the operator of the source or has certain connections with the operator. [48]

14. Other consequences of the noise e.g. dirt, dust. [50]

15. Other characteristics of the neighbourhood and whether they evoke negative feelings. [48] [50]

16. Whether the subject has a tendency to express critical or negative judgements. [53]

Great differences have been found between *individual's* responses to noise. One study [54] found this most noticeable in the differences to be found in individual's *attitudes* to noise and the *annoyance* which thereby arises. The researchers differentiated between responses by individuals and groups, and commented that although the physical parameters of the noise can explain a large proportion of variation between responses at different levels of noise, only a small proportion of variation between individuals across noise levels can be explained by physical parameters. This study [54] quoted a survey of Aircraft Noise Annoyance [55], where the Noise Number Index accounted for 78% of variation between different levels but only 21% of the variation between individuals across noise levels.

In a study of traffic noise [56] traffic noise accounted for 77% of variation in scores of dissatisfaction at different levels, but only 8% of variation between individuals across noise levels. However, a later study [57] reported that:

- most of the variation in noise dissatisfaction is not related to detectable individual differences, but to randomness in response to the measuring method - for example questionnaire methods.

- the influence of noise sensitivity on dissatisfaction is small.

3.2.3 Factors identified as not affecting a subjective response

Having established the factors which appear to have a causal relationship with subjective reactions to noise, some researchers have also identified the factors which have little bearing on a subjective reaction to a particular noise source. One study [42] concluded that pure sociological variables such as sex, age and socio-economic status do not appear to have a consistent effect on noise annoyance, a finding endorsed by [54] and [58] who investigated the effect of age. However, other researchers did find that the sex of the respondent had an influence in determining annoyance [59].

3.3 Methods for evaluating the impact of noise objectively

Researchers have for many years tried to establish methods of obtaining a figure which would indicate the loudness or noisiness of a sound on a linear scale. In a study of the literature related to assessments of subjective reactions to noise, the following phrases regularly appear: noise units, levels, indices and ratings. They are related in that they are concerned with assessment of noise, but they refer to different quantities. The following definitions are given for these phrases:

Unit - refers to a unit of measurement (e.g. Pascals - unit of sound pressure; watt - unit of sound power).

Level - it is the expression of a unit in logarithmic terms with respect to a reference value (e.g. 20μ Pa, 10^{-12} watts: dB re 20μ Pa).

Index - combines level with frequency weighting or tone corrections and with variation in time or frequency of occurrence. (e.g. A-weighted, B-weighted, C-weighted and D-weighted sound pressure level (L_{pA},L_{pB}, L_{pC}, L_{pD}), maximum A-weighted sound pressure level (L_{Amax}), Perceived Noise Level (PNL), tone corrected perceived noise level (TPNL), equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$), single event noise exposure level (L_{AX}), statistical level, L_{pN} (e.g. L_{p10}, L_{p50}, L_{p90}). The notation used to represent the noise indices is taken from ISO 1996/1 [60].

Ratings - brings into account the specific time of day and perhaps season and includes non-acoustic corrections (e.g. day/night equivalent sound level (L_{DN}), community noise equivalent level (CNEL), Corrected Noise Level (CNL) as in the BS4142 Method of rating industrial noise, Noise and Number Index (NNI)).

In this thesis, a variety of noise indices were correlated with subjective ratings of domestic appliance noise. The following sections will describe these indices.

3.3.1 Frequency-weighted indices

Weighting curves and associated levels were developed as a method to better evaluate the impact of noise upon the human ear (noting that the ear responds less well to frequencies below 500 Hz and above 8000 Hz than it does between those frequencies.) Originally 3 weightings were proposed. For sounds that were 'not loud' (below 55 dB) the A-weighting curve was defined. For sounds that were 'moderately loud' (55-85 dB) the B-weighting curve was defined. For 'loud sounds' (above 85 dB) the C-weighting curve was defined. For whichever weighting is used, the weightings are added to or subtracted from the one-third or octave band sound pressure levels and these levels are then summed to obtain a weighted sound level.

A-weighting (based on the 40 phon equal loudness contour) is used in measurements that relate directly to the human response to noise, both from the viewpoint of hearing damage and of loudness and annoyance. B-weighting is similar to the A-weighting in concept, corresponding roughly with the 70 phon equal loudness contour. It is seldom used as it offers no positive advantages over the A-weighting. The C-weighting corresponds roughly with the 100 phon equal loudness contour. It differs little from a flat weighting over the audio frequency range, and thus it is a reasonable approximation of the overall sound pressure level, L_p. Like B-weighting it offers little advantage over A-weighting, although it is a reasonable approximation of the overall sound pressure level due to the flat weighting.

D-weighting was proposed later for measuring aircraft noise and is derived from the 40 PNdB contour. It attributes far more significance to the 1000 to 10000 Hz frequency region than do the other weightings. It was intended to be a simple index of noisiness, as good as dBA, but has not shown itself to be sufficiently superior and thus is not used frequently. In Chapter 8, unweighted sound pressure level (L_p), along with A and D-weighted sound pressure levels, and A-weighted maximum sound pressure level of the appliances were correlated with subjective ratings.

3.3.2 Perceived Noise Level (PNL)

An endeavor has been made to quantify noisiness in an analogous way to loudness by means of a set of equal noisiness contours (see Figure 3.2). The concept was developed in the 1960s specifically to account for the noisiness of jet aircraft. The unit of noisiness, the noy, is defined as the noisiness in the band from 910 to 1090 Hz, centered at 1 kHz with a maximum sound pressure level of 40 dB. A noise with a noisiness of 3 noys is perceived to be three times as noisy as a noise judged to have a noisiness of one noy. The total perceived noisiness is calculated by:

$$PN = N_m + f\sum_{i=1}^{n} N_i - N_m \; noys \tag{3.1}$$

where

$PN =$ total perceived noise (noys)

$N_m =$ maximum perceived noise in the frequency bands measured (noys).

$N_i =$ each of the band perceived noisinesses, including N_m (noys)

$f =$ weighting factor for the bands chosen: $f = 0.3$ for octave bands and 0.15 for one-third octave bands

Noisiness level (PNL) is expressed in units of dB, PNdB.

$$PNL = 33.3\, log\,(PN) + 40\; PNdB \tag{3.2}$$

where:

$PNL =$ perceived noise level (PNdB)

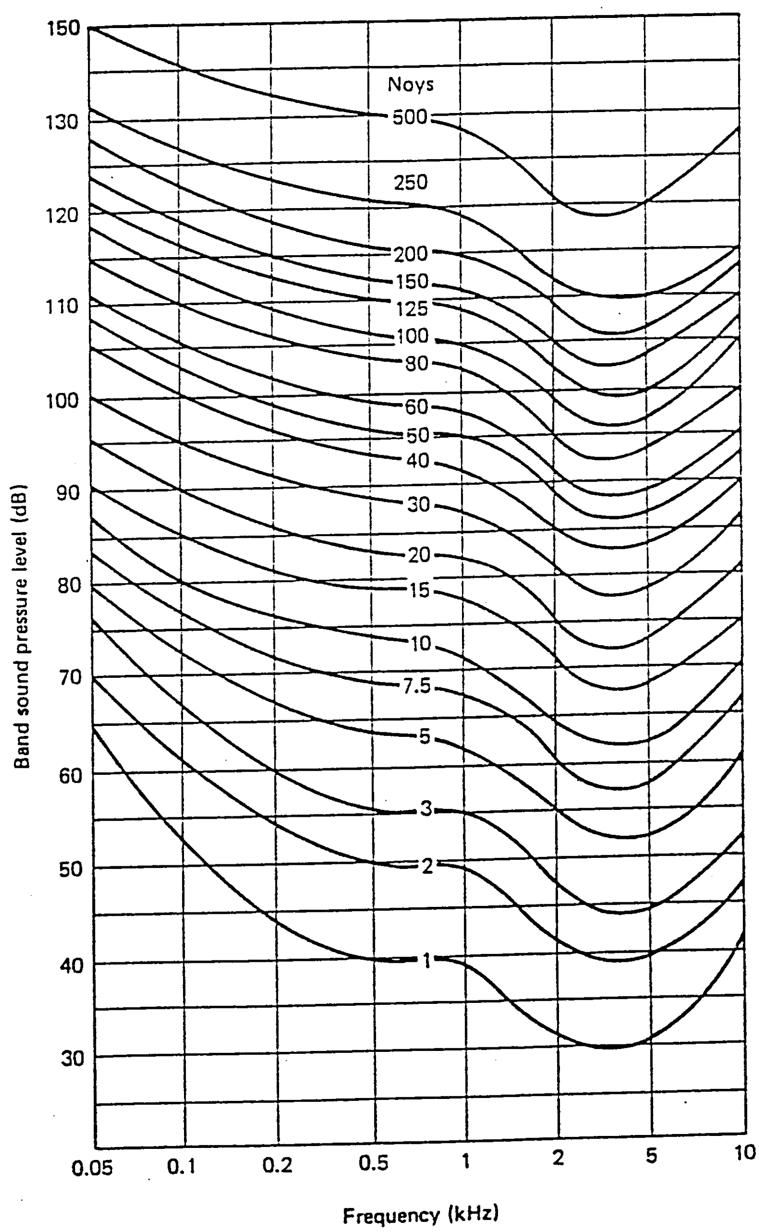


Figure 3.2 Perceived noisiness contours.[61]

PN = perceived noys

A desirable alternative method of arriving at the PNL would be to use either the A-weighted or D-weighted levels since these give direct readings of level as a function of time and so avoid the computations as described previously. Unfortunately the relationships are approximate:

$$PNL \simeq L_A + 13 +/- 3dB \; PNdB \tag{3.3}$$

and

$$PNL \simeq L_D + 7 \; PNdB \tag{3.4}$$

Tone corrected perceived noise level (TPNL)

As A-weighting does not perfectly account for the human perception of the frequency characteristics of a sound [62], other indices have been developed that attempt to improve the quantification of loudness and/or noisiness. One such index is the tone corrected perceived noise level. Where the sound spectrum has strong tonal components, measures like PNL underestimate the noisiness.

A correction method has evolved in relation to methods for describing aircraft noise heard on the ground [63]. This method (used when the noise spectrum shows pronounced irregularities such as pure tones) involves investigating the band sound pressure level of different frequency bands, assessing where the difference is greater than 5 dB and adding corrections to the perceived noise level (PNL) thus giving the tone corrected PNL (TPNL).

A similar method is used in the rating of industrial noise affecting mixed residential and industrial areas. If the noise contains a distinguishable discrete continuous note (whine, hiss, screech, hum etc) or there are distinct impulses in the noise (bangs, clicks, clatters or thumps), or if the noise is irregular enough in character to attract attention, then 5 dB is added to the measured level [64].

Judgement test have been conducted to determine the validity of pure tone corrections to perceived noise level [65]. Stimuli for these tests included broadband noise with single tones, modulated tones or multiple tones. These stimuli were presented at a constant duration of four seconds. Other stimuli included single tones in broad band noise for durations ranging from 4 to 32 seconds. The results of the judgement tests indicate that the perceived noise level with tone corrections adequately predicts the noisiness of these stimuli. In additions, for those stimuli varying in duration a duration correction is necessary.

3.3.3 Equivalent continuous A-weighted sound pressure level, ($L_{Aeq,T}$).

This is the value of the A-weighted sound pressure level of a continuous, steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula:

$$L_{Aeq,T} = 10\,lg\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{{p_A}^2(t)}{{p_o}^2}dt\right] \tag{3.5}$$

where:

$L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level, in decibels, determined over a time interval T starting at t_1 and ending at t_2.

p_o is the reference sound pressure (20μPa).

p_A *(t)* is the instantaneous A-weighted sound pressure of the sound signal.

As a measure of noise nuisance it is frequently criticised because it de-emphasizes occasional noisy events. The energy burst in a short burst of high-level noise is averaged out into quieter parts by the time averaging process. However it has been accepted as a means of assessing a variety of different noises.

3.3.4 Single event noise exposure level (SEL or L_{AX})

This is defined as the constant level which, if maintained for a period of one second, would deliver the same A-weighted sound energy to the receiver as the actual event itself. It is a logarithmic measure of total energy received, and is basically an equivalent continuous sound pressure level which is normalised to a time period of 1 second. Mathematically:

$$L_{AX} = 10\, log_{10} \left[\int_{-\infty}^{\infty} \left(\frac{p_A(t)}{p_{ref}} \right)^2 \cdot \frac{dt}{\tau_{ref}} \right] \tag{3.6}$$

where:

$p_A(t)$ is the instantaneous A-weighted sound pressure

p_{ref} is the reference pressure, 20μ pascals

τ_{ref} is the reference time, i.e. 1 second

In practice the the following is often used:

$$L_{AX} = 10\, log_{10} \left[\int_{t_1}^{t_2} 10^{\frac{L_A(t)}{10}}\, dt \right] \tag{3.7}$$

where t_1 and t_2 define the time interval in which the level remains within 10dB of its maximum during the event, and $L_A(t)$ is the instantaneous A-weighted sound pressure level. According to ISO 1996/1 [60], this formula is often referred to as sound exposure level (L_{AE}), which has the following formula:

$$L_{AE} = 10lg \frac{1}{t_o} \int_{t_1}^{t_2} \frac{{p_A}^2(t)}{{p_o}^2} .dt \tag{3.8}$$

where:

p_A *(t)* is the instantaneous A-weighted sound pressure

$t_2 - t_1$ is a stated time interval long enough to encompass all significant sound of a stated event

p_o is the reference sound pressure (20μ Pa)

t_o is the reference duration (1 second).

Since most noise events, other than impulses, last more than one second, the value of the single event noise exposure is usually higher than the maximum value of A-weighted sound pressure level during the event.

3.3.5 Conclusions with regard to subjective assessment of appliance noise

In this section the indices for evaluating subjective reactions to noise have been discussed. The question that emerges from this section is which index correlates the best with a subjective reaction to the noise? Two opposing views can be identified:

- the best indices are those found from psychophysical experiments to be the most highly correlated with human judgements of the noisiness of various different sounds. These experiments generally, but by no means always, rank the indices as follows, with the highest correlations stated first: tone corrected Perceived Noise Level, Perceived Noise Level, D-weighted sound pressure level, A-weighted sound pressure level, phon. These results are largely from experiments with aircraft noise.

- the difference in accuracy between the various indices in this list is not large - they are derived from experiments performed in the laboratory on small samples of the population, and that in real life the sound of any given source and the response to that sound are subject to alteration by many important factors not considered eg. day/night occurrence, fluctuating sound etc. Supporters of this standpoint maintain that indices like A-weighted sound pressure level are easily obtained with sound level meters and should be universally accepted.

There is agreement that a good noise index should consist of the following properties [44]:

1. The index must be sensitive to changes in the physical characteristics of the noise under investigation

2. The index must be able to produce numerical values for judgement conditions of equal noisiness or annoyance.

3. The index should be as convenient and as easy to measure as possible under the conditions imposed.

A number of these indices (A-weighted sound pressure level (L_{pA}), D-weighted sound pressure level (L_{pD}), sound pressure level (L_p), A-weighted sound power level (L_{WA}), equivalent continuous A-weighted sound pressure level ($L_{Aeq,30sec}$), maximum A-weighted sound pressure level (L_{Amax}), single event noise exposure level (L_{AX}), Perceived Noise Level (PNL) and Tone corrected Perceived Noise Level (TPNL)) were chosen to evaluate how well they correlated with a subjective reaction of domestic appliance noise.

3.4 Methods for obtaining subjective evaluations of noises

Two types of study methods provide most of the evidence about the effects of noise on people and the characteristics that mediate those effects:

- laboratory studies, where people react to controlled presentations of sounds in a rating situation
- field studies, where people report their feelings that have formed from years of exposure to noise in their every day home setting.

Evidence about the effects of detailed acoustic characteristics come almost exclusively from laboratory studies in which the characteristics of the acoustic environment can be closely manipulated and controlled. Thus such studies provide most of the information about the effects of tones, different frequency networks and duration of sound events. Field studies are the chief source of information about the effects of noise on people in the community.

Among the most commonly adapted methods used to provide evidence about subjective reactions to noise sources are:

- Magnitude estimation - The modern development of this method is attributed to S.S.Stevens [66] and there are two clearly distinguishable variations in the method. In the 'free' form of magnitude estimation, the subject responds to stimuli by assigning them numbers. The only restriction given by the instructions is that the numbers given to various stimuli should reflect the differences among stimuli. In the initial experiments performed by Stevens, loudness judgements were used and the instructions to subjects were: 'Try to make the ratios between the numbers you assign to different tones correspond to the ratios between the loudnesses of the tones. In other words, try to make the numbers proportional to the loudness as you hear it.'

The 'restricted' form of magnitude estimation involves the experimenter assigning a number to a given stimulus in the series. This stimulus becomes the standard stimulus and the remaining stimuli are judged in relation to the numerical value of the standard stimulus. Magnitude estimation techniques are, by nature, laboratory based techniques.

- Pair comparisons - Using this method, all the stimuli to be evaluated are presented to the subject in all possible pairs. The task of the subject is to judge whether one of the pair is of greater quantity than the other (where the quantity could be loudness, noisiness, annoyance etc.) The subject's response is a comparative judgement. The same subject may judge all pairs a large number of times on different occasions, or many subjects may judge all pairs only once.

- Method of constant stimulus differences - This method involves the use of a standard stimulus, whereby this stimulus is paired with each of a number of comparison stimuli. The task of the subject is to judge whether one member of the pair is greater or less than the other. The comparison stimuli are presented in a prearranged order which is unknown to the subject. It is usual for 4 to 7 comparison stimuli to be used, which have generally been selected through preliminary experimentation. A large number of repetitions is necessary.

- Method of adjustment - The aim of this method is to determine equivalent stimuli by active adjustment on the part of the subject. The subject is provided with a standard stimulus and with a second stimulus which is obviously different from the standard, being of greater or less quantity than the standard in some defined respect (loudness, noisiness, annoyance etc). The subject is required to adjust the second stimulus until it seems to him/her to be equivalent to the standard stimulus in that respect. The subject's adjustment is his/her judgement of the standard stimulus, and a number of such judgements are obtained. This method is also known as the method of average error, the method of reproduction (as the subject is attempting to reproduce a given stimulus) and method of equivalent stimuli.

- Numerical category scaling - This is one form of rating scale whereby a sequence of numbers, pre-selected by the experimenter, is supplied to the subject. The task of the subject is to assign to each stimulus an appropriate number. It is common for the series of numbers to be presented along with anchor terms - labels that describe the two extremes of the scale - although in some cases the verbal terms are used throughout the scale. The advantages of numerical category scaling are ([51] and [67]):

  1. The method can be used in the laboratory and field with equal facility, and a variety of different scales can be used for different purposes.
  2. It gives some relative indication of the relation between physical noise levels and subjective reactions.

  Two different types of scales are adopted. One type are known as *unipolar* scales, an example of which is given below:

```
 1    2    3    4    5    6    7    8    9
Not                Somewhat               Very
Annoyed            Annoyed                Annoyed
```

  The choice of numbers is arbitrary. The scale allows for feelings of annoyance only, on a rising scale of annoyance. As indicated by Loeb [46] the problem with this type of scale is that subjects may even like the stimulus and have no way of expressing this feeling. The alternative is a *bipolar* scale, an example of which is:

1	2	3	4	5	6	7	8	9
Very Pleasant				Neutral				Very Annoying

Again the choice of numbers is arbitrary. However there are a number of reservations about this choice of scale:

1. This type of scale should not be used unless there is an appreciable use of both poles, as otherwise one finds oneself with a number of scale categories rarely used and fewer ones over used.
2. It is often hard to specify the 'opposite' pole. What is the opposite of annoying?

These methods will be discussed in terms of the different subjective evaluations investigated in a study, as this often determines their precise format.

3.4.1 Judgements of Loudness

Experiments to determine subjects' ratings of loudness rely largely on similar magnitude estimation techniques. In general the method requires subjects to be presented with a standard sound (whose intensity remains fixed for the series of trials), and a number of comparison sounds, each of different intensity. The details of the loudness estimation depend very much on the study. In one study, the subject was given a number (1000) to describe the loudness of the standard sound and on this basis is asked to make a numerical judgement of each comparison sound (for example a comparison sound four times louder than the standard sound yielded a value of 4000 whereas one half the loudness resulted in a value of 500) [68].

In other studies, subjects were not given a base number for the standard sound, but were instructed to judge the loudness by assigning any positive number which corresponds to the loudness [69]. Some researchers enforced a limited scale for estimating loudness, for example 1 to 100, and subjects were instructed to consider 1 as representing the softest sound they had ever heard and 100 representing the loudest sound they had ever heard [70].

3.4.2 Judgements of Noisiness

Category Scaling - noisiness of domestic appliances

Experiments for determining subjects' ratings of noisiness, rely largely on category scaling methods. In the limited experimental work conducted into subjective reactions to domestic appliance noise, researchers have chosen to determine the noisiness of an appliance using category scaling methods. Harrison et al [15] in their assessment of the noisiness of household appliances, asked subjects to listen to the appliances under test and report their opinion of the noise level as:

`Noisy    Normal    Quiet`

Parsons [33] and Jacobs [32] asked subjects to rate the noisiness of appliance noise on a scale 0 - 9 where the extremes were labelled 'not noisy at all' (0) to 'extremely noisy' (9).

Category Scaling - noisiness of other noise sources

Investigations into the noisiness of other noise sources have used different types of category scales, that vary, not only in the number of categories, but also the labels used for the values on the scale.

In one study [71] a 4 point scale was used, with the following categories:

`very noisy    fairly noisy    slightly noisy    not at all noisy`

Different six point scales have been used in a number of studies.

- The following scale links noisiness with time proportions. [71]

  usually very noisy

  sometimes very noisy

  usually fairly noisy

  sometimes fairly noisy

  usually quiet

sometimes quiet

- No descriptions are attached to the first and last categories of the following scale, and subjects using this scale were instructed to regard them as extremes to provide a reference for the intermediate categories.

A	B	C	D	E	F
	Quiet	Acceptable	Noisy	Extremely Noisy	

  Subjects were permitted to interpolate between adjacent categories by marking both of them [72].

- The following two scales were used together [67] to determine the extent to which people were influenced by verbal description of the categories or alternatively merely fill the range of responses offered. The results showed that subjects formed their judgements largely on the basis of the category names of the rating scale.

Unnamed	Unnamed
quiet	very quiet
moderate	quiet
noisy	moderate
very noisy	noisy
unnamed	unnamed

Scales containing seven categories have been used by a number of researchers to determine noisiness. The scales were usually associated with pairs of words separated by the 7 point scale:

Necessary	1	2	3	4	5	6	7	Unnecessary
Bad	1	2	3	4	5	6	7	Good
Active	1	2	3	4	5	6	7	Passive

In one study [67] subjects were given 10 items - 8 non-noise - holidays, alcohol, politics, beauty, gambling, illness, food, litter; and two noise items

- aircraft noise and traffic noise, mixed among them. They were asked to describe each item in terms of the adjectives, and the scale.

A similar structure was used in another study [73], but this time subjects were developing a semantic profile of noisiness. They were asked to note their feelings about noisiness in terms of 11 pairs of words. This technique allows one to understand how a subject defines the term noisiness. 'x' represents a score on the scale. The scale is presented in see Table 3.1

Table 3.1 Semantic Profile of Noisiness [73].

	1	2	3	4	5	6	7	
Soft					x			Hard
Beautiful						x		Ugly
Violent		x						Gentle
Clean						x		Dirty
Sharp			x					Dull
Discordant		x						Harmonic
Strong		x						Weak
Pleasant						x		Unpleasant
Tense		x						Relaxed
Powerless					x			Powerful
Undesirable		x						Desirable

Magnitude Estimation and Noisiness

In only one study [74] was the magnitude estimation technique used to judge noisiness. Subjects were requested to make this judgement by comparing the noisiness of intermittent sounds to continuous sounds. However, no details were given about whether a fixed or free scale for the judgement was used.

3.4.3 Judgements of Annoyance

Experiments to determine annoyance reactions to noise sources have frequently been carried out, and a series of different annoyance scales have evolved over recent years. They are as follows:

Magnitude estimation and annoyance

As with judgements of loudness and noisiness, researchers have attempted to evaluate annoyance reactions using magnitude estimation techniques. In one study [58] subjects were asked to listen to the sound of a jet aircraft at a prescribed level and to regard that sound as representing 10 units of annoyance. Immediately after this presentation another sound was presented and the listener was asked to indicate the number of units of annoyance that he thought was appropriate to it, bearing in mind the standard sound was 10 units. Another study did not assign a level for judgement of the standard sound. Subjects simply assigned a number to each stimulus sound proportional to the magnitude of his or her perception [75]. Subjects were asked to base their judgement on the total overall effect and not on peak levels alone. The instructions were:

> Please try to make the ratios between the numbers you assign to the different sounds correspond to the ratios between the annoyance of the sounds. In other words, try to make the numbers proportional to the annoyance.

Simple Annoyance 'Bother' Questions

The following is an example:

`When indoors do you ever hear any of these noises?`

	Hear	Not Hear	Bother	Does not bother
Aircraft				
Trains				
Cars				

`For each noise heard does noise from..... bother or disturb or annoy you at all?`

This type of annoyance scale has been used often ([76], [77], [78]).

Category Scaling of Annoyance

Following an investigation of social surveys on noise annoyance, one researcher [79] concluded that people's responses could be measured along a scale of annoyance running from 'not at all annoyed' to 'very much annoyed', with intermediate responses arranged along a numerical annoyance scale (whose length varied from 4 to 7 or more steps). The two extreme responses were usually named. The numerical degrees of subjective annoyance were then analysed.

In recent studies of annoyance, the descriptors and intervals used have been variable and non-standard [80]. Two types of category scales have been used to determine annoyance reactions. One is the *Graphic Rating Scale*. Such a scale takes the following form:

```
How annoying did you find the noise?

Not annoying at all   1  2  3  4  5  6  7  Very annoying
```

This type of scale has been used extensively in subjective experiments. Researchers adapt the scale for their own purposes by altering the labels and length of the scale. A 7 point scale was used in one study [81] to rate subject's annoyance to various noises e.g. cars, trucks, neighbourhood noise - where 1 represented low levels of annoyance and 7 represented high levels. Another study used a 7 point scale with extremes labelled 'scarcely annoying at all' (1) to 'unbearably annoying' (7) [45]. A seven point scale, used in another study, had the extremes labelled 'not at all annoying' and 'very annoying' and the mid point labelled 'moderately annoying' [81].

A 9 point bipolar scale was used in another study, with the end points labelled 'extremely agreeable' and 'extremely disturbing'. In this study a bi-polar scale was used following a pilot study in which a unipolar scale was used and it found that subjects wanted to rate positively. Scales of 10 points have been used in a number of studies ([82],[83], [84], [85], [86]). In these studies only the extremes of the scale were labelled, the choice of wording being: not annoying at all/not annoyed at all/not at all: for 0; to extremely annoying/extremely annoyed/extremely: for 9.

Only one scale of 11 points was identified [87]. The scale ranged from 0 - 10 and subjects were asked to rate how annoyed they were by 13 common noises in the environment. No indication was given as to whether the extremes of the scale were labelled.

An annoyance rating scale was developed by Pearson and Hart [88] (see figure 3.3)

```
--- Unbearable and intolerable
-
-
--- Extremely annoying
-
-
--- Very Annoying
-
-
--- Quite Annoying
-
-
--- Annoying
-
-
--- Moderately annoying
-
-
--- Somewhat annoying
-
-
--- Slightly annoying
-
-
--- Noticeable but not objectionable
```

Figure 3.3 Single Adjective Scale of Annoyance [88].

Using this scale, subjects were allowed to indicate their response anywhere along the continuum. Therefore 25 steps were determined to cover effectively the range of responses observed.

The other type of category scale used in assessment of annoyance is the *Labelled Rating Scale.*

This takes the form of a question with a series of labelled responses in the form of words. For example:

```
Does the noise of aircraft bother or annoy you?
Very Much
Moderately
A little
Not at all
```

Again researchers have altered this type of scale to suit their own purposes, the alterations being in the labels used and the number of possible responses. Researchers usually adopt a mixture of response lengths. Some researchers include questions allowing for 2 responses [89], for example:

```
Are you generally annoyed by traffic noise?     Yes    No
```

The use of questions with three responses was adopted by [90] e.g.:

```
How annoyed are you with this noise?
Not very
Rather
Very annoyed
```

Questions with four labelled responses are much more popular and adopted in most studies of annoyance where questionnaires are completed ([91], [89], [92], [87], [93]). Such questions include:

```
How annoyed were you with the noise?
Very
Somewhat
Not too
Not at all annoyed
```

```
Does the noise of the train bother or annoy you?
```

Very much
Moderately
A little
Not at all

Does aircraft noise annoy you?
Very often
Rather often
Sometimes
Never

A 5 point labelled scale was used in one study [67] associated with a series of questions related to annoying situations, compiled of 30 non-noise and 10 noise ones. The response categories were:

Extremely annoying
Moderately annoying
Slightly annoying
Not annoying
Have not been in this situation

A six point labelled scale of annoyance was used in one study where the categories were [94]:

quite
noticeable
intrusive
annoying
very annoying
unbearable

In one study, the variability and non-standard features of annoyance scales was highlighted, and an attempt was made by the researcher to produce a standardised annoyance scale, using a variation of the Thurstone Scaling Technique [80]. The scale possessed descriptions that marked clear semantic distinctions, which were roughly equidistant from each other. The scale consisted of the following 7 descriptors:

```
Tremendously annoyed
Greatly annoyed
Considerably annoyed
Medium annoyed
Partially annoyed
A little annoyed
Not at all annoyed
```

Activity interference index questions

This type of scale was devised by Guttman and has since been used extensively ([55], [77] and [78]). It is comprised of the following structure:

Does.......noise ever:	Yes	No	N/A
Wake you up			
Interfere with listening to TV/radio			
Make the house shake			
Interfere with conversation			
Interfere with/disturb other activities			

After ascertaining whether there is any disturbance, the questions often determine how the person finds the disturbance to be (very, moderately or a little annoying).

A different structure was devised to investigate annoyance through activity interference [51]. A scale was developed consisting of 42 items - each comprised of an activity (reading, cooking) and two rating scales of eleven points. Subjects indicated on the first scale how much they enjoyed or disliked the activity and in the second whether being in noisy surroundings increased or decreased their enjoyment or dislike. The response on the second scale had to be made with reference to the response on the first scale.

Adjective Pair Scale

This was a scale developed and used by Anderson [51] and was composed of a number of adjective pairs and an eleven point rating scale in-between the pairs. This type of scale is useful in assessing what aspects of a noise give rise to annoyance, and why and how the annoyance is caused. For example, in describing noise, the following adjectives were used: Annoying-Pleasing, Good-Bad, Uncomfortable-Comfortable.

3.4.4 Judgements of Dissatisfaction

Subjects' satisfaction with a particular noise has also been assessed. Again, using category scaling methods a 7 point scale was adopted [56] [57] and the extremes were labelled 'definitely satisfactory' and 'definitely unsatisfactory' This subjective assessment was also used [4] in the survey of noise annoyance around London (Heathrow) Airport, and the results led to the development of NNI (Noise and Number Index) for assessing aircraft annoyance in the community.

3.4.5 Judgements of Acceptability

A limited number of researchers have examined judgements of acceptability of noise using the techniques previously described.

Magnitiude estimation and Acceptability

Subjects heard a pair of sounds and were asked to indicate which was the most acceptable noise of each pair [95]. Then the subjects were presented with a pair of noises (one of which was the noise judged to be most acceptable on the first experiment) and they were asked to adjust the level of the second noise until both noises were equally acceptable.

In another laboratory study subjects were required to alter levels of noise until they became unacceptable [96]. Subjects were asked firstly to adjust a speech recording until it was at a level they would like to listen to it. Then a traffic noise signal was played to subjects and they were required to adjust the intruding time-varying traffic noise signal until they considered it to be just unacceptable for relaxed listening to speech.

Category scaling of Acceptability

Category scaling provides a useful technique for assessing acceptability. The scale can be quite small and demand only a yes/no response [86] or it can consist of a number of labelled points - for example: subjects were asked to rate a noise in terms of its acceptability using the following scale [71]:

```
satisfactory
unsatisfactory
comfortable
uncomfortable
good
poor
```

3.4.6 Summary of the review of noise rating

This section has considered a variety of methods for obtaining subjective evaluations of noises. Overall, there are two such methods: magnitude estimation and category scaling; which can be used to obtain reactions of loudness, noisiness, annoyance, dissatisfaction and acceptability. The techniques are adapted depending on the evaluations under investigation. Magnitude estimation involves the subjective determination of the loudness, annoyance, acceptability or noisiness of one sound, based on their perceptions of another sound. Category scaling involves a scale (numerical or verbal) along which subjects indicate their perception of the sound. The scales differ in length (from 4 to 11 points) and in the labels used along the scale.

3.5 Discussion

It is evident that the human response to sound is:

- extremely complex

- is determined by acoustic and non-acoustic variables of equal importance
- can be assessed in a multitude of different ways.

Before designing any subjective experiments to determine a subjective reaction to domestic appliance noise, a number of issues must be resolved which have been highlighted throughout this chapter.

1. Which subjective judgements should be investigated? - Loudness, noisiness, annoyance, dissatisfaction, or acceptability.
2. Are there any other judgements applicable to an assessment of domestic appliance noise?
3. What are the possible causal factors involved in evoking a particular subjective reaction that warrant special investigation in this study?
4. Which noise index will best correlate with a subjective evaluation of domestic appliance noise?
5. How will the subjective reactions be measured? - Magnitude estimation, pair comparisons, numerical category scaling etc. If numerical category scaling is used, what length of scale is most appropriate?

Each of these questions will now be assessed.

3.5.1 Which reaction/judgement should be assessed during the subjective experiments?

Because of the nature of this study - Assessment of Domestic Appliance *Noise* loudness ratings would not generate the responses to allow an adequate assessment of the noise from domestic appliances, because loudness is a judgement of the strength of the sound and this was not the subjective reaction under investigation. Loudness and noisiness judgements have been shown to be very different ([37] [40]), but this is very dependent on the context in which they are assessed. So loudness judgements were not assessed in the study. In the review of the literature, the concept of annoyance was discussed with some reservations. According to Kryter [38] the concept of annoyance is usually associated with man's subjective response to noise, and this response is diversified. Kryter therefore proposed the concept of noisiness. In another study [44] the researcher questioned whether annoyance judgements could be obtained in the laboratory with the same success as noisiness judgements.

Considering these comments, and the nature of the study, it was decided that that subjects would be asked to judge the noisiness of appliances during the subjective experiments.

Annoyance reactions were considered to be important, however, in order that the acoustic factors that elicit such a reaction could be investigated. Therefore subjects were also asked to give a rating of annoyance to each appliance.

As very little is known about subjective reactions to domestic appliance noise, it was decided that it would be of interest to include assessment of acceptability related to the noise level of the appliance - this would enable investigation of the factors that determine whether the noise level of a domestic appliance is acceptable or not to the subjects, and whether there is a level above which all appliances are judged unacceptable.

The descriptors used to identify subjective reactions to domestic appliance noise (noisiness, annoyance and acceptability) were not defined for subjects for fear of biasing subjects with a certain interpretation. Therefore subjects were using the scales in a relative fashion and no absolute perception of the attributes investigated was obtained.

3.5.2 Are there any other judgements applicable to an assessment of domestic appliance noise?

In section 3.2.2 were discussed non-acoustic factors affecting a subjective reaction to noise. Included among these was the view of one researcher [42] who felt that the individual's attitude towards the usefulness of the equipment generating the noise was of importance. Usefulness is an appraisal that is not related to the noise of the appliance. It was felt that an appraisal of usefulness could be a contributory factor of a particular subjective reaction, either to a reaction in terms of noisiness, or in terms of other judgements such as annoyance or acceptability. Thus a subjective appraisal of usefulness of the appliances was included in the subjective experiments.

3.5.3 What are the factors involved in determining a particular subjective reaction that warrant investigation in this study?

From examination of the literature in section 3.2, a number of factors mentioned were considered potentially important in the assessment of subjective reactions to domestic appliance noise.

1. The overall sound pressure level - would subjects rate appliances noisier if A-weighted sound pressure levels were higher?

2. Duration of the stimulus - would the length of time the appliance was operated affect the subjective reaction?

3. Different ratings for different groups of stimuli - In one study [72] the researchers correlated A-weighted sound pressure levels (resulting from pass-bys from private cars, commercial vehicles and motorcycles) with subjective ratings and found that if the ratings for all vehicles were plotted together, there was poor agreement. But if plotted separately, i.e. for private cars and for commercial vehicles there was good agreement. They concluded that the poor correlation from grouped responses stemmed from the fact that each regression line had a different slope, showing that observers used a slightly different rating scale for each class of vehicle.

   In another study [97] ratings vs sound level (dBA) for aircraft noise, were compared with the results of a study of motor vehicle noise [98]. They found a marked difference at higher noise levels. It appeared that people rated aircraft noise on a totally different scale with more tolerance for aircraft. A vehicle creating a noise of 90 dBA was rated excessively noisy but an aircraft also creating 90 dBA was only rated moderate to noisy. Would subjects use a given rating scale differently depending on the appliance type?

4. Tonal components - it is commonly accepted that those sounds in whose spectra components with high frequencies occur are more annoying than sounds which are devoid of these components. Would this be the case for domestic appliances?

5. User/Listener condition - in Chapter 2 (section 2.7) the results were reported of a very small experiment to determine the subjective reaction to domestic appliance noise [15]. From the study they found that the degree of annoyance experienced by a person seems to be dependent to some extent on whether the person is actually using the appliance. Although the information reported in the study is rather incomplete, the concept of possible user/listener differences in reactions was considered sufficiently interesting to include in this study.

3.5.4 Which unit of noise will best correlate with a subjective evaluation of domestic appliance noise?

According to one study [44], although an A-weighted index is convenient, it is also recognised that sounds of equal dBA, equivalent continuous A-weighted sound pressure level, or Perceived Noise level do not evoke equal noisiness or annoyance responses.

The use of A-weighted indices in evaluating annoyance reactions has also been criticized as the use of dBA blurs spectral features of the sound which are significant for the perception of annoyance [43].

The previous studies of domestic appliance noise have correlated subjective response with A, B, and C-weighted sound pressure level, equivalent continuous A-weighted sound pressure level, Perceived Noise Level, maximum A-weighted sound pressure level and mean sound pressure level. High correlations were obtained for all of the decibel scales. In one study PNL obtained the highest correlation with subjective response to noisiness. [32].

It was thus decided to investigate subjective responses to domestic appliance noise using most of the noise indices described in this chapter (sound pressure level (L_p), A-weighted sound pressure level (L_{pA}), D-weighted sound pressure level (L_{pD}), maximum A-weighted sound pressure level (L_{Amax}), equivalent continuous A-weighted sound pressure level ($L_{Aeq,30sec}$), single event noise exposure level (L_{AX}), Perceived Noise Level (PNL), and A-weighted sound power level (L_{WA})).

3.5.5 How will the subjective reactions be measured?

McKennell [55] used a Guttman scaling technique to combine activity disturbance questions. Though the technique is still defended, most investigators acknowledge that any of several different techniques are useful. However, Mckennell also argues that complex psycho-social measurement techniques have been used, when it is evident that the simple categories scale which requests the respondent to make a choice between stated degrees of annoyance/noisiness etc, is generally adequate. Another investigation [41] concluded that it did not seem worthwhile to complicate the measurement of aircraft noise by calculation formulas (e.g. Perceived Noise Level) when a sound level measurement of maximum A-weighted sound pressure level was not only sufficient but superior.

Having considered the methods used to obtain subjective evaluations, it was decided that the numerical category scaling technique would be used to assess subjective reactions to domestic appliance noise. The other methods are particularly time consuming and they involve many repetitions to obtain the final assessment. Numerical category scaling, although not the most accurate of the methods described, is the quickest and most convenient to use. The crucial question is what length should the scale be?

There are conflicting arguments about the length of scale adopted. Borsky [86] used a 10 point scale because in past studies with fairly high noise levels, 4 point annoyance scales resulted in annoyance ratings clustered at the top of the scale. Borsky considered there would be a better distribution of responses with a 10 point scale.

A 7 point scale of dissatisfaction was adopted in another study [57]. The researchers argued that a 7 point scale could adequately discriminate between different levels of noise exposure. The general shapes of the distributions of responses they obtained were not distinguishable from normal except to the extent that the high levels of exposure produced skewness in the direction of high dissatisfaction.

Justification for the length of rating scale in the present study

After studying the literature it was quite clear that the choice of scale (both length and labels) was very random with no obvious rules for selection. In general most researchers stated the length of scale adopted for their particular study, but gave no justification for their choice. In most of the studies investigated, there was no conclusion drawn about the possible inadequacies or merits of the length of rating scale chosen, with the following exceptions:

1. [41] - this study found clustering of annoyance responses associated with aircraft noise, at the upper end of the 5 point scale. This suggested that an annoyance scale with a larger range than 5 points might be better.

2. [56] - from this study it was concluded that, for the purpose of further scientific study of noise nuisance the 7 point scale of dissatisfaction is superior to the 4 point scale of bother, and it invariably yields higher correlations between noise level and subjective response. However, it is unclear whether the superiority of the 7 point scale of dissatisfaction is attributed to the increased length or choice of labels.

3. [15] - the 3 point scale used in this study was considered to have severely restricted the results.

4. [57] - the 7 point scale of dissatisfaction was considered to have clearly distinguished between the noisy and quiet urban areas where the interviews took place.

5. [99] - it was concluded that relatively small numbers of categories should generally be used - where there is no psychometric advantage in a large number of scale categories (greater than 9 - 12) there may be a loss of discriminative power and validity with fewer than 5 categories. The 5 point category scale was found to be the most reliable, and the 7 point category scale was the most accurate.

After considering the comments/criticisms regarding scale length, a 7 point scale was adopted for assessing noisiness for the following reasons:

1. According to Guilford [100], using too short a scale could results in coarse ratings.

2. Alternatively too long a scale would exceed the discriminatory powers available to the subject.

3. According to Miller [101], subjects can only make seven discriminations on a unidimensional scale.

4. Parsons [33] has recommended a 7 or 10 point scale for the assessment of domestic appliances with higher sound pressure levels (sound pressure levels higher than those of refrigerators or fan heaters).

5. A pilot study revealed that, for the range of appliance noise levels to be investigated, the 7 point scale was quite adequate.

For the assessment of annoyance and appraisal of usefulness, subjects were asked to use a 4 point scale was used, which is usual when the judgements are being assessed in a questionnaire format. It will be seen in Questionnaire 1 (Appendix I) that annoyance was assessed using the following 4 point scale:

```
Very much
Moderately
A little
Not at all
```

In Questionnaire 2 (Appendix J) annoyance was assessed using the following 4 point scale:

`Not at all annoying`
`A little annoying`
`Moderately annoying`
`Extremely annoying`

The choice of adjectives in verbal category scales has been carefully scrutinized [80]. Indeed Schultz [79] discussed the equivalence of very much, highly and extremely annoyed. In view of this and the fact that extremely annoyed was chosen as the anchor for upper end of scaling in other work, it was decided to use extremely in questionnaire 2. For assessing acceptability a simple Yes/No response was considered to be adequate.

The ideas discussed in this Chapter form the basis of the research hypotheses to be investigated during this study. These are discussed in more detail in Chapter 4.

Chapter 4

Research Hypotheses

4.1 Introduction

The aim of the subjective experiments was two fold:

1. To identify the factors that evoked a particular subjective response when a panel of subjects was asked to rate the noise of a domestic appliance.

2. To establish which unit of measurement correlates best with a subjective reaction to an appliance noise.

The hypotheses investigated during the course of the subjective experiments were developed to identify and explain the variation in subjective reaction that occurred when subjects were presented with noises from different appliance types. Throughout this chapter, each hypothesis investigated will be described, along with an explanation for its inclusion in the study.

In statistical examinations, it is common practice to examine a *statistical hypothesis*, which is referred to using the terms: H_0 and H_1, which represent the *null* and *alternative* hypothesis respectively. However, these hypotheses have specific interpretations in a statistical sense. The null hypothesis is a null hypothesis about some parameter of statistical distribution. For example, a null hypothesis may be that $x = 0$ and a statistical test will be performed to demonstrate if this is the case. In this study, the hypotheses are much more general, and are not statistically specific (i.e. they do not refer to a particular parameter of statistical distribution). This type of hypothesis is often referred to as a *research hypothesis.* For such a hypothesis it is not correct to refer to H_0 and H_1 because statistical tests are used to investigate an idea and not a statistical distribution. Therefore these labels are not used, and the word *hypothesis* will be used to refer to the research hypothesis.

4.2 Hypotheses to demonstrate the validity and reliability of the experimental data

Hypothesis 1

A subject's rating of the noisiness of domestic appliances will vary with the presentation of appliance noises with differing physical characteristics.

The reason for suggesting this hypothesis is, very simply, to demonstrate that different noises and noise levels will evoke a different rating of noisiness. This must be demonstrated to be true otherwise the results of any subjective experiments would be meaningless, as all the different appliance noises would be rated the same.

Hypothesis 2

A subject's rating of the noisiness of domestic appliances will be consistent between two experimental sessions.

This hypothesis will be investigated as a check on the consistency of subjects' noisiness ratings of different appliance noise levels in different sessions. If average ratings of a given appliance noise are not consistent then it will difficult to find an index that correlates with subjective reaction.

4.3 Hypotheses relating objective quantities to subjective ratings

The aim of this series of hypotheses was to identify the particular physical characteristics of an appliance noise that might evoke a particular subjective reaction.

Hypothesis 3

A subject's rating of noisiness will depend on whether the subject is using the appliance or listening to it.

(This hypothesis is included in this section as there is an objective quantity under investigation - namely the change in noise level and character with distance from the appliance for user/listener positions. It is acknowledged, however, that this hypothesis is comparing subjective ratings given under user conditions with subjective ratings given under listener conditions).

Individuals not only use domestic appliances, but they are also present when many domestic appliances are being used by other individuals in a household. The purpose of this hypothesis is to investigate any differences between the rating of noisiness when a subject is using an appliance and also when the same subject is listening to the appliance being used (by another person). If there is found to be a relationship, will it be common across all types of appliances or related only to specific types? If subjects rate appliances as noisier when they are listening to them, rather than using them what implications will this have for the acoustic labelling of domestic appliances with their sound power level only?

Hypothesis 4

A subject's rating of the noisiness of an appliance will be conditioned by the duration of its operation.

The reason for suggesting this hypothesis is to investigate the possibility that the amount of time an appliance is in use will influence ratings of noisiness. For example, will subjects become aclimatised to the noise of an appliance the longer it is operated and thus find the noise level more acceptable? Alternatively, does elongation of exposure to appliance noise evoke the opposite effect and become more disturbing the longer the period of operation? The results of this hypothesis could demonstrate possible inadequacies of a noise index for labelling appliances that does not account for a time factor.

Hypothesis 5

A subject's rating of the noisiness of an appliance will vary in a way that is highly correlated to A-weighted sound power level, (L_{WA}).

In the light of the EEC directive [21] recommending the acoustic labelling of domestic appliances using A-weighted sound power level, it is important to investigate how A-weighted sound power level index correlates with a rating of noisiness.

Hypothesis 6

A subject's rating of the noisiness of an appliance will be related to some noise index (other than L_{WA}) such as L_{pA}, L_{pD}, PNL, L_{Amax}, $L_{Aeq,T}$ and L_{AX}.

It is important to determine which noise index correlates best with a rating of noisiness as this may help in the understanding of the factors evoking such ratings. For example, subjects may give a higher noisiness rating to an appliance containing pure tones, or subjects may rate according to the maximum sound pressure level experienced during operation of an appliance.

Hypothesis 7

A subject's rating of annoyance evoked by an appliance will be related to some noise indices such as L_{WA}, L_{pA}, L_{pD}, PNL, L_{Amax}, $L_{Aeq,T}$ and L_{AX}.

This hypothesis aims to investigate whether the feeling of annoyance is related to the physical measurement of the noise such as A-weighted sound pressure and A-weighted sound power levels or equivalent continuous A-weighted sound pressure level and to determine which index correlates best with annoyance. Are appliances judged to be more annoying as they become noisier, or are annoyance and noisiness independent factors affecting a subjective reaction? (See also Hypothesis 9).

Hypothesis 8

A subject's rating of noisiness will vary according to the family of appliances under investigation.

This hypothesis was suggested to investigate whether noisiness ratings are associated with particular families of appliances. As was discussed in Chapter 3, section 3.5.3, different ratings were attributed to different vehicle types [72]. In another study, ratings for aircraft and vehicle noise were quite different even though A-weighted sound pressure level values were identical [97]. Hair dryers might therefore be rated as quieter than vacuum cleaners, regardless of their sound levels (for example A-weighted sound power level as measured according to ISO 3741 [17]). Or all food processors might be rated noisier than all liquidisers, again regardless of the sound level emitted. If this concept is demonstrated to occur, then perhaps a separate labelling scheme should be adopted for each family of appliances.

4.4 Hypotheses relating different subjective ratings to each other

The aim of this series of hypotheses was to identify non-objective quantities that cause particular subjective reactions, and to establish which rating scale is the most consistent according to the various noise indices to be investigated.

Hypothesis 9

A subject's rating of the noisiness of an appliance will be determined by the rating of annoyance evoked by the appliance.

The aim of this hypothesis is to establish the extent to which a feeling of annoyance evoked by an appliance will be reflected in the subject's noisiness ratings for that appliance. If the subject is very annoyed by the appliance, will this contribute towards higher ratings of noisiness than if the appliance does not evoke such a degree of annoyance?

Hypothesis 10

A subject's rating of the noisiness of an appliance will be related to an appraisal of the usefulness of that appliance.

Generally speaking domestic appliances are labour-saving devices and are useful in our everyday lives. If an appliance is considered useful, is a subject more likely to rate its noisiness lower than for an appliance not considered to be useful? This hypothesis is included to investigate the effect of an appraisal of usefulness on a subject's noise rating.

Hypothesis 11

A subject's appraisal of the usefulness of an appliance will be related to a rating of the acceptability of the noise of the appliance.

This hypothesis aims to establish the extent to which a subject's appraisal of the usefulness of an appliance influences the subject's decision as to whether the appliance noise would be acceptable, in his/her own home. It is based on the question: 'Would you consider the appliance to be acceptable, from the point of view of noise, for use in your home?' which is included in Questionnaire Two (Chapter 6, section 6.7.2). Are subjects prepared to accept the noise level emitted because of the utility provided by the appliance?

Hypothesis 12

A subject's rating of the noisiness of an appliance will be determined by the subject's rating of the acceptability of the noise of the appliance.

The aim of this hypothesis is to establish the extent to which ratings of noisiness are related to those of acceptability of the appliance noise. Will acceptability of the appliance noise decrease with an increase in noisiness? Or is noisiness not one of the factors involved in the subject's decision whether or not to accept the noise of an appliance.

Hypothesis 13

A subject's rating of annoyance evoked by an appliance will be related to the subject's rating of the acceptability of the noise of the appliance.

This hypothesis aims to establish the extent to which the annoyance generated by a particular appliance noise, influences a subject's decision as to whether the appliance noise would be acceptable in his/her own home. Again, it is based on the question:'Would you consider this appliance to be acceptable, from the point of view of noise, for use in your home?'.

Hypothesis 14

A subject's appraisal of the usefulness of an appliance will be related to the rating of annoyance evoked by the appliance noise.

This hypothesis aims to establish the extent to which an appraisal of the usefulness of an appliance influences ratings of annoyance, or the extent to which the two concepts are independent. Will annoyance ratings be completely independent of any feelings a subject has towards the usefulness of the appliance?

4.5 Required Experiments

To examine these hypotheses, two series of experimental studies were carried out:

- experiments to determine the index values of domestic appliance noise - namely: L_{pA}, L_{pD}, L_p, L_{WA}, PNL, $L_{Aeq,T}$, and L_{AX} as described in Chapter 5.

- experiments to determine the subjective reactions to domestic appliance noise - namely judgements of noisiness, annoyance and acceptability of the appliance noise, and appraisals of the usefulness of appliances, as described in Chapter 6.

Each hypothesis was investigated by examining the results of interactions within and between these two experimental studies. The results are presented in Chapter 8.

Chapter 5

Objective measurements of domestic appliance noise

Before examining possible relationships between objective measures of domestic appliance noise and subjective reactions to that noise, it is necessary to measure the noise output of the domestic appliances. This can be achieved by:

- quantifying how much noise an appliance makes by determining its A-weighted sound power level (L_{WA}).
- quantifying how much noise we actually hear, by determining the A-weighted sound pressure level (L_{pA}) (we hear sound pressure but it is caused by the sound power emitted from the source).

The first section of this chapter will describe the measurement of the A-weighted sound power levels of a selection of appliances and the levels obtained, while the results of the A-weighted sound pressure level measurements (*in situ*) will be discussed in the second section.

5.1 Determination of the sound power level (L_{WA}) of domestic appliances.

When trying to quantify human response to sound such as 'noisiness' or 'annoyance', sound pressure level in dB is the quantity usually measured

[102]. However, the sound pressure measured is dependent on the distance from the source and the acoustic environment (sound field) in which sound waves are present. This in turn depends on the size of the measuring room and the absorbing surfaces. So by measuring sound pressure it is not possible to quantify how much noise a machine makes. Therefore it is necessary to determine the sound power of a machine as this quantity is more or less independent of the environment and is a descriptor of the emission from a sound source.

The formula for sound power level (defined as ten times the logarithm to the base ten of the ratio of the source power to the reference power, usually taken as 10^{-12} watts) is [12]:

$$L_W = 10\, log_{10} \frac{W}{W_0} \tag{5.1}$$

where W is the power emitted and W_0 is the reference power (10^{-12}).

Sound power level data are useful for the following investigations [103]:

1. for calculating the approximate sound pressure level at a given distance from a machine operating in a specified environment.
2. for comparing the noise radiated by machines of the same and different types and sizes.
3. for determining whether a particular machine complies with an upper limit of noise specification.
4. for planning in order to determine the amount of transmission loss or noise control required under certain circumstances.
5. for engineering work to assist in developing quiet machinery.

The sound power level, which gives the total sound power radiated by the source in all directions, is usually measured in one-third octaves or octaves. Together with directivity measurements (where directivity is a measure of the difference in radiation with direction around the source and is also measured for each frequency band), A-weighted sound power level measurements describe completely the strength of a noise source.

In helping to standardise sound power level measurements, the series of International Standards with the title 'Acoustics - Determination of sound power levels of noise sources', marked as ISO 3740 - 3746 were issued between 1975 and 1983. They are as follows:

ISO 3740 - Guidelines for the use of basic standards and for the preparation of noise test codes. [104]

ISO 3741 - Precision methods for determination of sound power levels for broad band sources in reverberation rooms. [17]

ISO 3742 - Precision methods for determination of sound power levels for discrete frequency and narrow band sources in reverberation rooms. [18]

ISO 3743 - Engineering methods for determination of sound power levels for sources in special reverberation rooms. [23]

ISO 3744 - Engineering methods for determination of sound power levels for sources in free-field conditions over a reflecting plane. [19]

ISO 3745 - Precision methods for determination of sound power levels for sources in anechoic and semi-anechoic rooms. [20]

ISO 3746 - Survey methods for determination of sound power levels of noise sources. [105]

The choice of any particular method is guided by the following factors:

1. the size of the noise source under investigation.
2. the test environment available.
3. the character of the noise produced by the source.
4. the highest grade of accuracy required.
5. the acoustical data needed to fulfill the purpose of the measurement.

In 1982 the International Electrotechnical Commission released its own standard IEC 704-1 - Test code for the determination of airborne acoustical noise emitted by household and similar electrical appliances. Part 1: General Requirements. [22]. This standard was concerned with objective methods of engineering accuracy for determining sound power levels of airborne acoustical noise specifically for domestic appliances.

For the purpose of this study, the choice of standard for measuring sound power levels was limited largely by the choice of test room and equipment requirements. As suitable facilities were not available at the Open University, contact was made with the Building Research Establishment, who offered the use of their anechoic and reverberation rooms. This restricted the choice of standard for measuring sound power level to ISO 3741, 3742 and 3745. After studying each of these standards, and discussing equipment requirements with a senior scientific officer it was decided that the measurement of sound power level would be performed in accordance with ISO 3741. Directivity information was obtained separately, using the anechoic chamber.

In choosing this method (Precision method for determination of sound power levels for broad-band sources in a reverberation room), it may seem that one is ignoring the advice of IEC 704-1 which recommends the use of ISO 3743 or ISO 3744 for determining the sound power level of household appliances. However the test code does specify: [22]

> Not included in this standard are methods for determining sound power levels with precision accuracy .....specified for example in ISO Standards 3741, 3742 and 3745; they may, however be applied if the appropriate instrumentation and test environment is available.

5.1.1 Sound Power Level Measurements according to ISO 3741

According to ISO 3741 there are two laboratory methods for determining the sound power radiated by an appliance using a reverberation test room -

the direct method:

> That method in which the sound power level is calculated from the measured sound pressure levels produced by the source in a reverberation room and from the volume and reverberation time of the room.

and the comparison method:

> That method in which the sound power level is calculated by comparing the measured sound pressure levels produced by the source in a reverberation room with the sound pressure levels produced in the same room by a reference sound source of known sound power output.

As noted previously, the comparison method (using a reference sound source) has the advantage that the reverberation time of the room need not be measured for the calculation of the sound power level thus minimising errors. Therefore the comparison method was chosen for this study.

5.1.2 Problems associated with the determination of sound power levels in reverberation rooms

Before describing the measurements in detail, it is important to be aware of the reservations regarding the use of reverberation rooms for sound power level measurements. In the reverberation room at low frequencies, the sound power level determined is lower than when determined in the free field. This phenomenon has been investigated [106] and one explanation was attributed to inaccuracies of reverberation time determination from the decay curves. The discrepancies seemed to arise at low frequencies (50 - 500 Hz), and the values obtained using the diffuse field were always lower than those obtained from the free-field. However when sound power level measurements were made using a standard reference sound source to compare the sound power output of an unknown source in the reverberation room (the comparison method), several sources of error were minimised:

- Problems concerning the early decay rate (where discrepancies arise when measuring either early decay or decay from -5 to -35 dB as recommended by ISO) are avoided as reverberation time measurements are not required for the calculation of sound power level.

- If it is possible to place the reference sound source in the same position as the source under test, the influence of the source position in the room is to a great extent minimised.

- By using the same microphone positions for the measurement of both the reference sound source and the unknown source, also, the errors introduced by using a limited number of microphones are partly overcome.

These recommendations were adopted for the sound power level measurements in this study.

5.1.3 Measurement Uncertainty

The uncertainties involved in the determination of the sound power levels according to ISO 3741 are presented in Table 5.1, expressed as the largest value of the standard deviation in decibels. These standard deviations take into account the cumulative effects of all causes of measurement uncertainty.

Table 5.1 Uncertainty in determining sound power levels of broad-band sources in reverberation rooms [17].

Octave band centre frequencies	One-third octave band centre frequencies	Standard deviation
Hz	Hz	dB
125	100 to 160	3.0
250	200 to 315	2.0
500 to 4000	400 to 5000	1.5
8000	6300 to 10000	3.0

5.1.4 The Reverberation Room

Figure 5.1 shows the plans of the reverberation room (and also the anechoic room which adjoins the reverberation room) at the Building Research Establishment. The walls and ceiling of the reverberation room are plastered and gloss-painted. The are *no* parallel surfaces in the room (see Figure 5.2). The volume of the room is approximately 1300m^3, and the surface area is approximately 728.32m^2.

To increase diffusion of the sound in the room, curved perspex sheets are hung in the sloping ceiling. The reverberant room is structurally independent of both the ground and the anechoic room, being an isolated box structure supported on resilient mountings (ribbed rubber mat type) located along the two ends of the reverberant room floor, with jacking spaces to allow replacement of the mountings if necessary.

5.1.5 Test Room Requirements according to ISO 3741

Room Volume

The recommended volume of the reverberation room depends very much on the lowest frequency band of interest. For this study, the lowest frequency band of interest was 100 Hz third-octave. This requires that the minimum room volume be 200 m^3. If frequencies above 3000 Hz are included in the frequency range of interest, the volume of the test room should not exceed 300 m^3. The volume of the reverberation room at Building Research Establishment was 1300 m^3 (approximately). In larger rooms such as this, air absorption may cause an undesirable reduction in the uniformity of the reverberant field in the highest frequency bands within the frequency range of interest. Thus, the data above 3.15 kHz is likely to be less accurate than that below 3.15 kHz. However, for domestic appliances, most of the sound energy falls below 3.15kHz, and it is felt that this factor did not have a significant affect on the accuracy of the measurements.

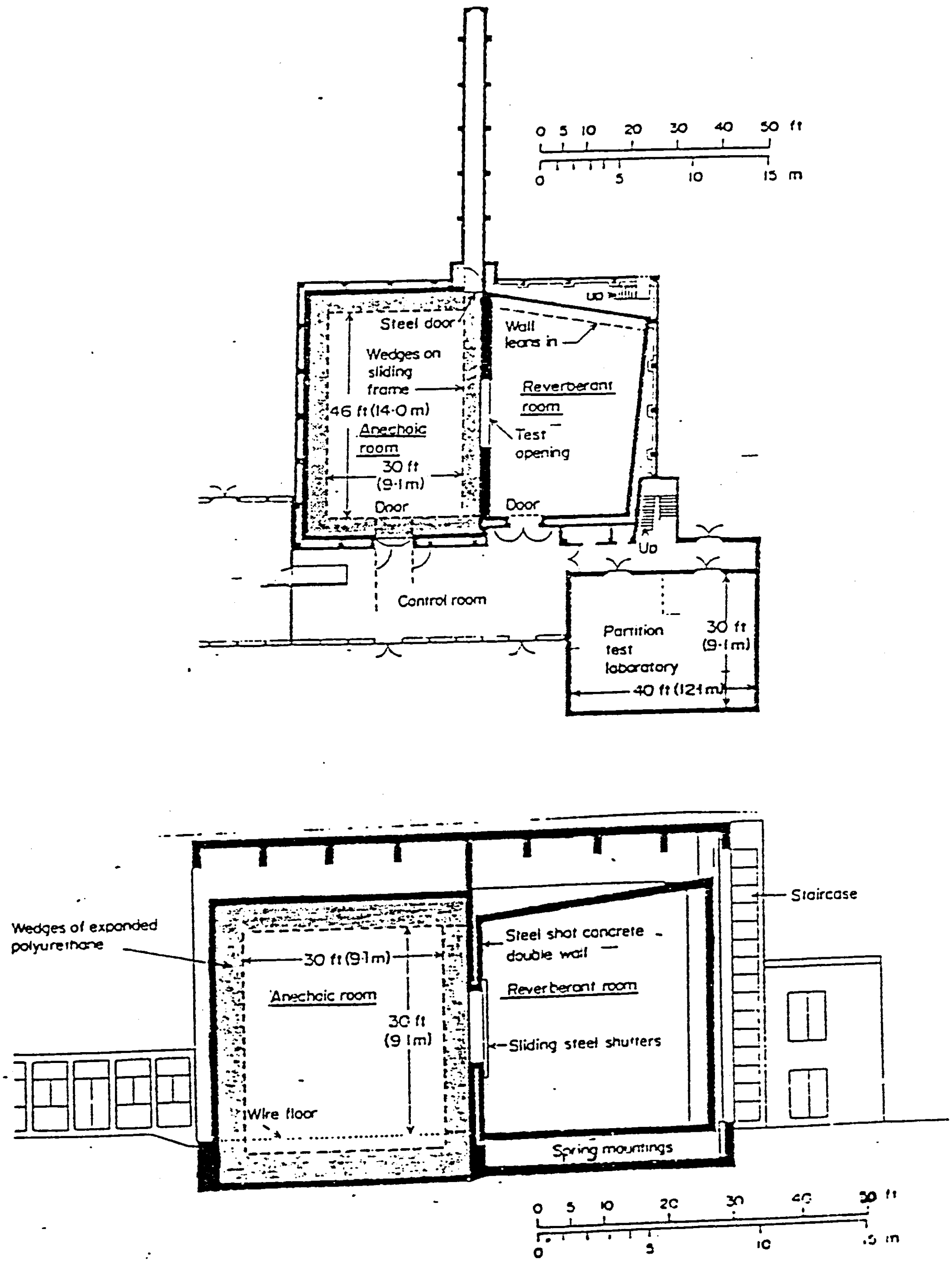


Figure 5.1 Plan of the reverberation and anechoic rooms (aerial) and section through the rooms.

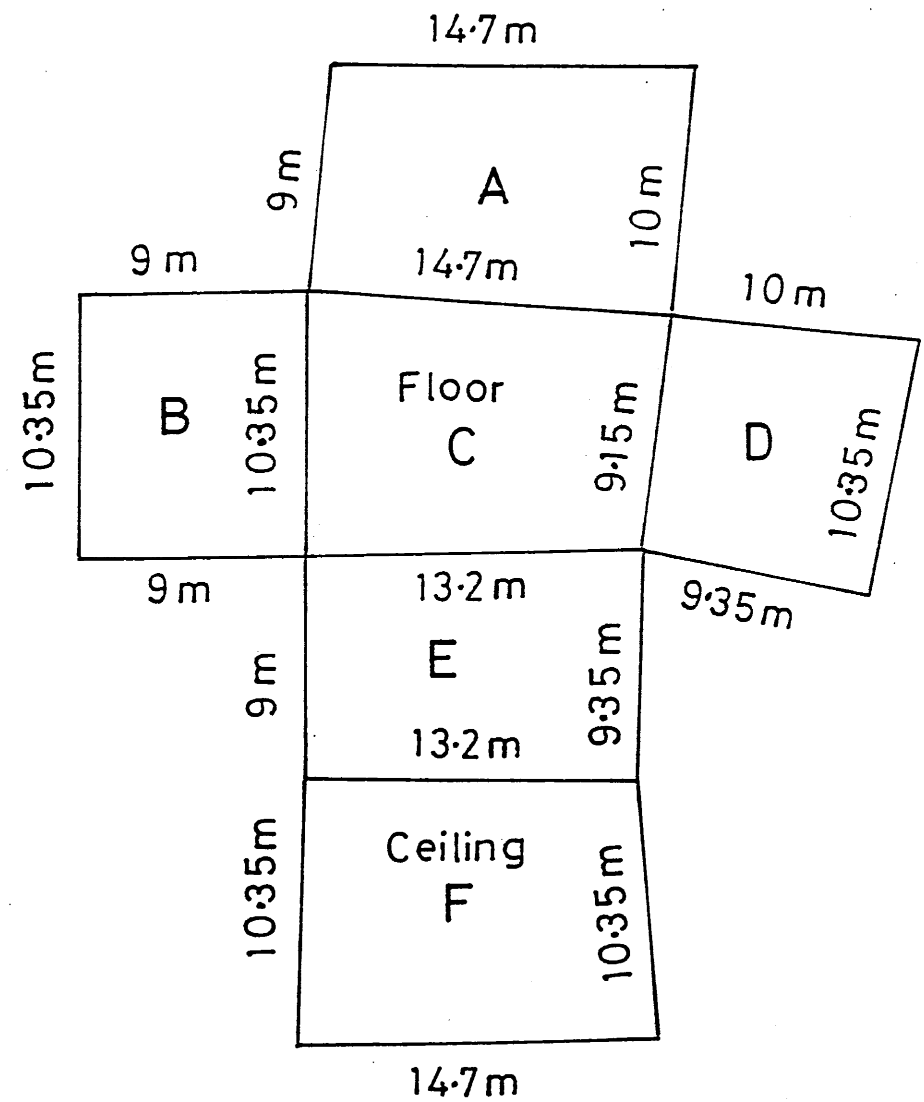


Figure 5.2 Dimensions of the reverberation room.

Criterion for room absorption

The sound absorption coefficient of the surfaces of the reverberation room must be small enough to ensure an adequate reverberant field. Therefore it is recommended that the average absorption coefficient of all surfaces of the reverberation room should not exceed 0.06 over the frequency range of interest. The average absorption coefficient was determined by the following equations:

$$\alpha = \frac{A}{S} \; and \; A = \frac{0.161V}{T} \tag{5.2}$$

where:

α = average absorption coefficient.

A = total sound absorption.

S = surface area.

V = volume of the reverberation room (1300 m^3).

T = reverberation time in seconds.

The reverberation times were measured for three frequencies - 100 Hz, 1000 Hz and 3150 Hz. (For a detailed description of the reverberation measurements see Appendix A). Using these reverberation times, the average absorption coefficient for each frequency were calculated. The results are presented in Table 5.2.

Table 5.2 Reverberation times and average absorption coefficients of the reverberation room.

Frequency Hz	Time (seconds)	α
100	19.60	0.015
1000	12.86	0.022
3150	5.46	0.053

In each case the average absorption coefficient was less than 0.06.

The standard states that the minimum distance between the sound source (domestic appliance or reference sound source) and the nearest microphone position *shall not be less than*:

$$d_{min} = 0.08\sqrt{\frac{V}{T}} \tag{5.3}$$

where:

V is the room volume in cubic metres.

T is the reverberation time, in seconds.

For the lowest frequency of interest:

$$d_{min} = 0.08\sqrt{\frac{1300}{19.6}} = 0.65m$$

Care was taken to ensure that the minimum distance between the sound source and the nearest microphone position was not less than 0.65m.

Criterion for background noise level

The standard recommends that the background noise level shall be at least 6 dB, and preferably 12 dB below the sound pressure level to be measured in each frequency band within the frequency range of interest. Measurements were regularly taken of the background noise within the room. Where the background level is within 6 - 10 dB of the level of the source under investigation the recommended corrections were made to the data (see section 5.1.9).

Criteria for temperature and humidity

The air absorption in the reverberation room varies with temperature and humidity, particularly at frequencies above 1000 Hz. The temperature θ (in degrees Celsius) and the relative humidity RH (in percent) were monitored during the sound pressure level measurements, and were observed to remain stable (i.e. they did not differ by more than $\pm$ 10 % during the measurements).

5.1.6 Instrumentation

> Instrumentation shall be designed to determine the mean-square value of the sound pressure level in octave and/or one-third octave bands averaged over time and space. [17]

The comparison method required that a Bruel and Kjaer Type 4202 Reference Sound Source was used. This reference sound source operates on an aerodynamic principle. The fan generates wide band sound through turbulence. It has a fixed broad-band sound power output and is calibrated in one-third octaves and octaves. The sound emitted is practically independent of temperature and humidity and is quite stable as long as the voltage supplied to the source is controlled. The only disadvantage with using this source is that it has poor efficiency and therefore requires high electrical power (0.5 - 1 kW) to achieve a reasonably high sound level. This power can at times be so large that it causes a temperature increase above permissible levels in the measurement room. This was not a problem in the measurements reported here. The temperature of the room was monitored throughout the experiments and it did not rise above permissible levels. The reference sound source fulfilled the requirements as stated in Annex B ISO 3741 [17] (that it should be capable of being calibrated and should be omnidirectional, as far as possible, over the frequency range of interest).

The instrumentation of the measuring system consisted of the following equipment:

Three half inch microphone capsules - Bruel and Kjaer Type 4165

Three microphone preamplifiers - Bruel and Kjaer Type 2619

Two microphone power supplies - Bruel and Kjaer Type 2807

An acoustic calibrator - Bruel and Kjaer Type 4230

Microphone channel switching box - Bruel and Kjaer Type SBK0510

Digital frequency analyser - Bruel and Kjaer Type 2131

Interphase switching box - Imae T-Switch

Alphanumeric printer - Bruel and Kjaer Type 2312

Digital cassette recorder - Bruel and Kjaer Type 7400/WHR38

Figure 5.3 shows the equipment configuration used. The microphones were calibrated at the beginning and end of each experimental session on each day. Drifting observed throughout the experimentation period was negligible.

5.1.7 Source location and mounting

ISO 3741 standard gives the following advice regarding source location:

> The source to be tested shall be placed in the reverberation room in one or more positions that are typical of normal usage ....If a particular position is not specified, the source shall be located at least 1.5 m from any wall of the room.

With regards source mounting it states:

> Whenever a typical condition of mounting or use exists for the equipment under test, that condition shall be used or simulated for the test, if practicable. Equipment normally installed on a table or stand shall be so mounted during the test.

Due to the imprecise instructions regarding location and mounting of the source, IEC 704-1 [22] was consulted for more detailed information. In accordance with ISO 3741, table type appliances eg. liquidisers, food mixers and food processors were mounted on a sturdy table, above the same position as the reference sound source (approximately 1m above the ground). This was to enable simulation of the positioning in the subjective experiments. IEC 704-1 recommends that hand-held appliances such as hair dryers should be resiliently suspended or mounted. Thus these appliances were suspended by ropes which passed through metal poles in the ceiling. The ropes were secured around the appliance and a rope was secured to the floor to prevent movement of the appliance. In this way the appliance was suspended

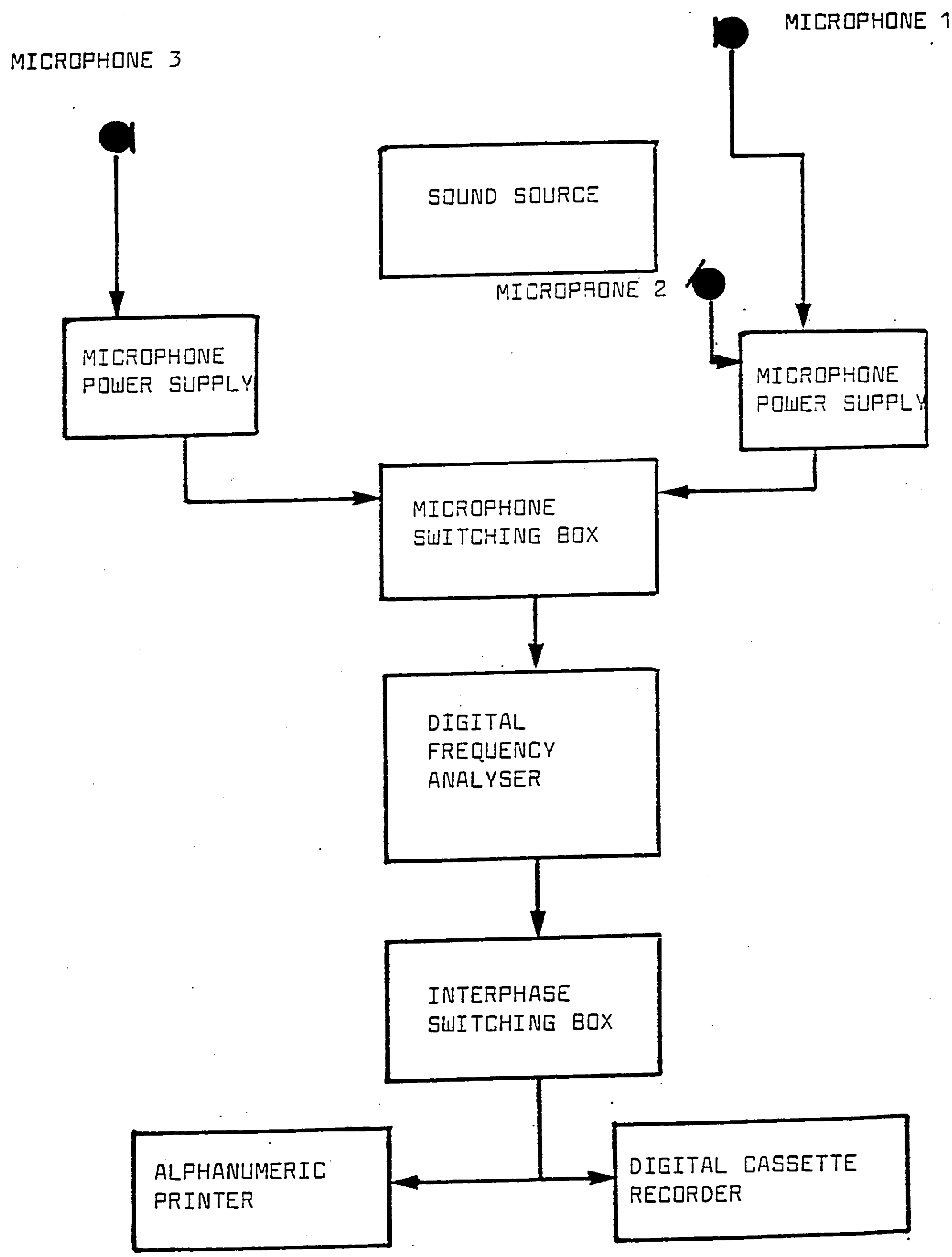


Figure 5.3 Equipment required for sound power level measurements in a reverberation room according to ISO 3741.

approximately 1.5 m above the ground. Care was taken to ensure that the ropes did not cover any of the air intakes of the appliance.

IEC 704-1 recommends that floor treatment appliances (vacuum cleaners) be placed on a piece of specified floor covering, representing practical applications, and having the smallest dimensions necessary for placing the appliance in use. A small piece of carpet was used for the testing of vacuum cleaners. It was typical bedroom-type carpet, of short pile. For the cylinder-type vacuum cleaners, a retort clamp and stand was used to clamp the hose to the carpet in a position approximating normal use.

Which ever appliance was being tested, care was always taken to ensure that the source was always at least 1.5 m from any wall of the room. The source and reference sound source were always located in the same position. Figure 5.4 shows the location of the source.

Operation of the source during measurements

ISO 3741 specifies that during the measurements, the source shall be operated in a specified manner typical of normal use. It suggests four operational conditions, one or more of which may be appropriate:

1. device under normal load.
2. device under full load (if different from 1).
3. device under no load.
4. device under operating conditions corresponding to maximum sound generation.

It is recommended that the source be in a stable operating condition before any noise measurement is made.

Where applicable, the appliances were tested in accordance with condition 1. Load conditions applied only to kitchen-type appliances - food mixers, liquidisers and food processors. The 'load' used for these appliances was a bread crumb and water slurry. This consisted of bread crumbs, made up to 550 ml with water (a quantity sufficient to cover the blades or whisks

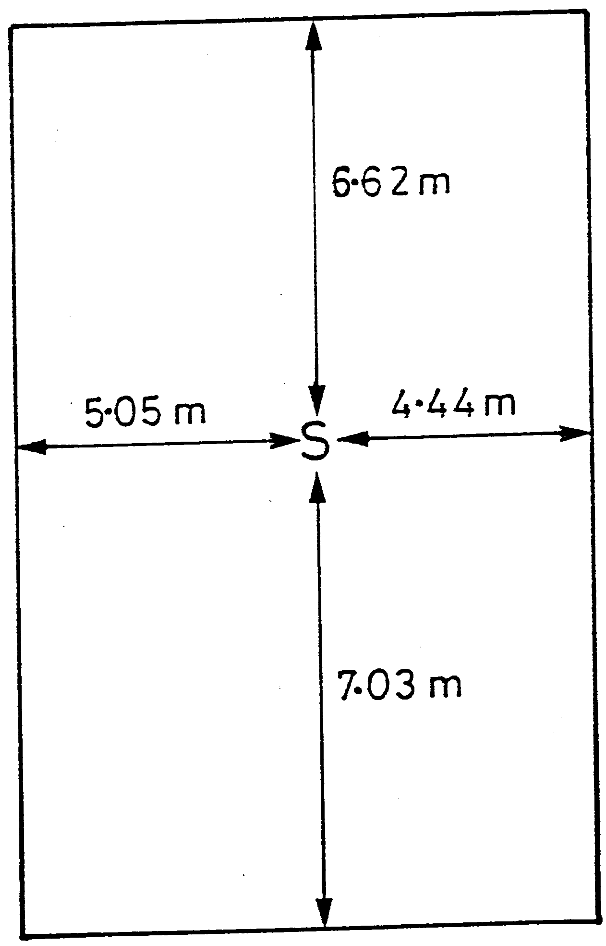


Figure 5.4 Location of the source and reference sound source in the reverberation room.

of all the kitchen appliances tested). A similar load was used by Jackson and Leventhall [8]. Although it is appreciated that such a load would not create the maximum noise generating conditions for all appliances (particularly food processors, where the shreading of vegetables would be expected to generate higher noise levels), it was the only load that would retain the same consistency throughout the testing period.

> Experience has shown that loading and operating conditions of practical use are seldom suitable for determination of noise emission due to the poor reproducibility. [22]

An identical load was used during the operation of appliances in the subjective experiments (see Chapter 6, section 6.3).

Where appliances had multiple speed settings, measurements were usually taken during a selection of speeds. For appliances with two or three settings, measurements were taken for each speed. For appliances with more than three speed settings, measurements were taken for the medium and fastest speeds. However, there were exceptions to this: some of the appliances (for example food processors) are designed to be used on the fastest setting for only limited periods. Because of the length of time involved in obtaining sound pressure levels for each appliance, it was not always possible to operate appliances on the fastest setting. (Allowing for the stable operating conditions of each source also increased the duration of the measurement period by approximately ten minutes - the time recommended for stabilizing).

5.1.8 Location of the reference sound source

It is recommended that the reference sound source be mounted on the floor of the reverberation room at least 1.5 m away from any other sound reflecting surface such as a wall or the source being evaluated. For each measurement, the reference sound source was placed in the exact location of the source under test (the floor of the room was marked to indicate the exact location of source and reference sound source.)

5.1.9 Measurement of mean-square sound pressure

Microphone positions

ISO 3741 suggests two possible microphone configurations:

- where the microphone is traversed at constant speed over a path at least 3 m in length while the signal is being averaged on a mean-square basis.
- where an array of at least three fixed microphones or microphone positions is spaced at least a distance of $\frac{\lambda}{2}$ apart (where λ is the wavelength of the sound wave corresponding to the lowest frequency of the frequency band of interest) and the output of the microphones is scanned automatically and/or averaged on a mean-square basis.

Because of equipment limitations, an array of three fixed microphones was used. The centre frequency of the lowest frequency band of interest was 100 Hz. The corresponding λ is given by

$$\frac{344}{100} = 3.44m$$

344 m/s being the speed of sound in air. Thus the required minimum distance of the microphones from each other was:

$$\frac{\lambda}{2} = \frac{3.44}{2} = 1.72m$$

Figure 5.5 shows the distances adopted for floor standing appliances. Figure 5.6 shows the distances adopted for suspended/table top appliances. (The difference is as a result of the use of the table which altered the distances between source and microphone).

The standard also states that no point on the array shall be closer than $\frac{\lambda}{2}$ to any room surface of the reverberation room, where λ is the wavelength of sound corresponding to the centre frequency of the lowest frequency band of interest. Thus microphone heights were important, and had to be higher than 1.72m. Also the location of the microphone array must be within that

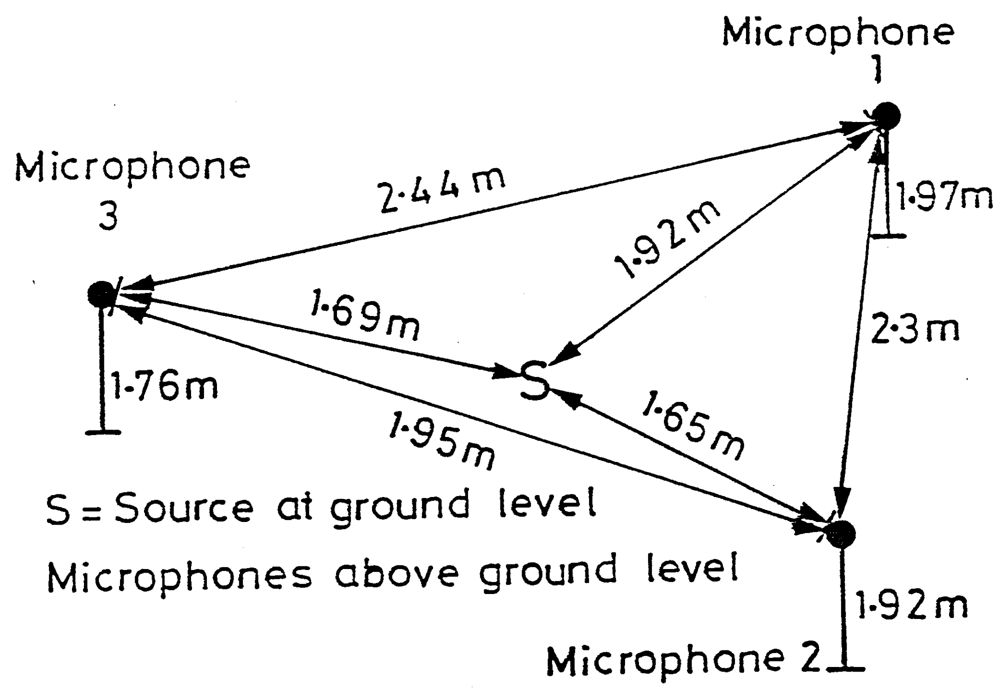


Figure 5.5 Microphone and source configuration for floor standing appliances.

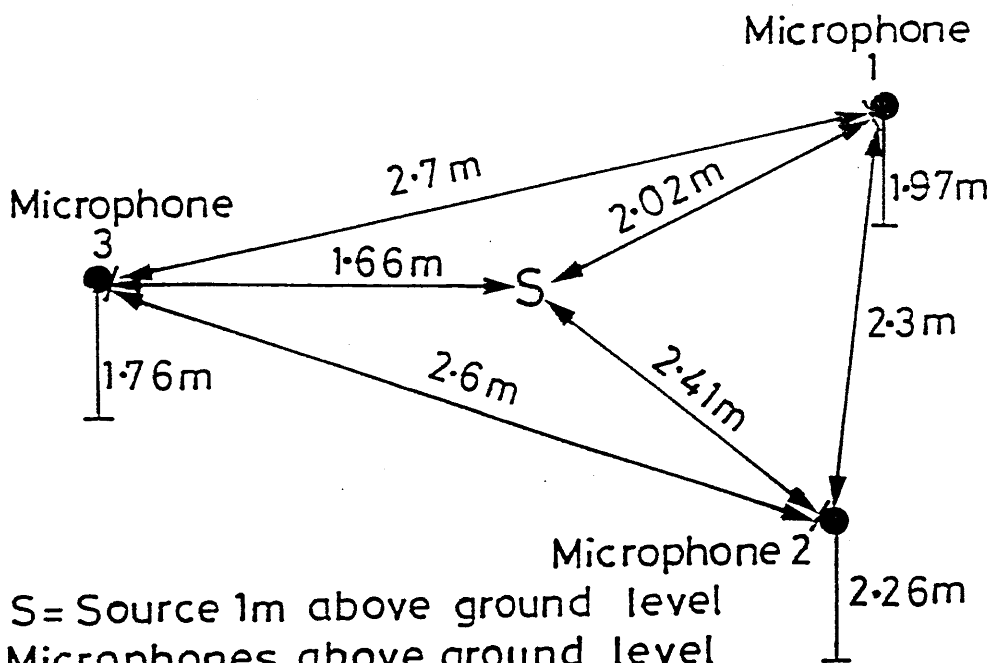


Figure 5.6 Microphone and source configuration for suspended/table top appliances.

portion of the test room where the reverberant field dominates. The criterion to ensure that the microphone array is within the reverberant field has previously been discussed in subsection 5.1.5 (where the minimum distance between the sound source and microphone position is greater than 0.65m). For floor standing appliances, the heights of the microphones together with distance from the source can be seen in Figure 5.5. For table top and hand held (suspended) appliances the information is presented in Figure 5.6.

Required data and conditions of measurements.

According to ISO 3741, the determination of the mean-square sound pressure of each individual microphone position shall be made for each frequency band within the frequency range of interest, by measuring:

1. The band pressure levels produced by background noise (which includes the noise from support equipment and internal electrical noise).

2. The band pressure levels during operation of the source being tested.

3. The band pressure levels during operation of the reference sound source.

The microphone positions were identical for each of these measurements and the results were recorded on a digital cassette recorder and alphanumeric printer.

Period of Observation

The period of observation for averaging of the readings is dependent on the frequency band of interest. For the frequency bands centered on or below 160 Hz, it is recommended that the observation period is at least thirty seconds. For the frequency bands centered on or above 200 Hz, the recommended observation period is at least ten seconds. Regardless of frequency, during these measurements the digital frequency analyser was programmed to average over thirty two seconds at each microphone position.

Correction of Background Sound Pressure Level

The measured band pressure levels must be corrected for the influence of background noise according to Table 5.3.

Table 5.3 Corrections for background sound pressure levels.

Difference between sound pressure level measured with sound source operating and background sound pressure level alone	Correction to be subtracted from sound pressure level measured with sound source operating to obtain sound pressure level alone
dB	dB
<6	measurement invalid
6	1.3
7	1.0
8	0.8
9	0.6
10	0.4
>10	0.0

If the background noise level is less than 6dB below the sound pressure level with either the reference sound source or the equipment operating, then the accuracy of the measurements is reduced and no data should be reported. In no instance was a correction necessary during the period of measurements.

5.1.10 Calculation of the mean band pressure level

Because an array of three individual microphone positions was used, the levels (corrected for background sound pressure levels) for each frequency band of interest should be averaged by using the following equation:

$$L_p = 10\, log_{10} \left[\frac{1}{N} \sum_{i}^{i=1} 10^{0.1 L_i} \right] \qquad (5.4)$$

where:

L_p is the mean band pressure level in decibels. Reference: 20μPa.

L_i is the pressure level resulting from the *ith* measurement, in decibels. Reference: 20μPa.

N is the total number of measurements in the band (i.e. three).

5.1.11 Calculation of Sound Power Level by the Comparison Method

Unlike the direct method of calculating sound power level, where the reverberation time of the room is essential to the calculation of sound power level, the comparison method does not require reverberation time measurements and the procedure is relatively simple. The sound power level produced by the source in each octave or one-third octave within the frequency range of interest may be calculated from the following equation:

$$L_W = L_p + (L_{Wr} - L_{pr}) \tag{5.5}$$

where:

L_W is the band power level of the source under test, in decibels. Reference: 1pW

L_p is the band pressure level of the source under test, in decibels. Reference: 20μPa.

L_{Wr} is the band power level of reference sound source, in decibels. Reference: 1pW.

L_{pr} is the mean band pressure level of reference sound source in decibels. Reference: 20μPa.

The sound power levels for each one-third octave band were A-weighted by adding/subtracting the appropriate figure and then plotted for each appliance investigated. The A-weighted sound power levels for each one-third octave band, for each appliance, are presented in Appendix B in tabular form.

It is also possible to calculate the overall A-weighted sound power level for each appliance from one-third octave band power levels using the following formula:

$$L_{WA} = 10\,log_{10} \sum_{j=1}^{jmax} 10^{0.1[(L_W)_j + C_j]} \qquad (5.6)$$

where $(L_W)_j$ is the level in the *jth* one-third octave band and C_j represents A weighting values to be added to or subtracted from the level in the *jth* one-third octave band.

5.1.12 Directionality measurements

To describe the strength of a noise source completely, the sound power level and directivity of the source are required. The directivity of an appliance is a measure of the difference in radiation of sound with direction around the source. Directionality measurements were carried out on the household appliances under test. An appliance is considered to exhibit directional characteristics of noise emission when the difference in radiation of sound with direction varies by more than 6 dB from one direction to another (Annex B ISO 3741 [17]). As many of the appliances of a given type have similar dimensions and proportions, the following selection from each family of appliances was investigated:

- Kenwood Chef A901 Food Mixer - Speed 4
- Prestige L2001 Food Processor
- Philips HM3060 Food Mixer - Speed 2
- Philips TX2000 Liquidiser
- Hoover U2002 (upright) Vacuum Cleaner
- Electrolux ZA65 (cylinder) Vacuum Cleaner
- Braun Supercompact 1200 Hair Dryer - Speed 1
- Boots MD2 Hair Dryer - Speed 2

- Clairol 1200 Hair Dryer - Speed 1

The measurements were carried out in Building Research Establishment's anechoic room (dimensions of which can be seen in Figure 5.1), using the following equipment:

A turntable - Bruel and Kjaer Type 3922.

A half-inch microphone capsule - Bruel and Kjaer Type 4165.

A microphone preamplifier - Bruel and Kjaer Type 2619.

A measuring amplifier - Bruel and Kjaer Type 2607.

A band pass filter set - Bruel and Kjaer Type 1615.

A chart level recorder - Bruel and Kjaer Type 2307.

Figure 5.7 shows the equipment configuration. The turntable was placed on a sturdy stool in the anechoic room (the stool was standing on a piece of hardboard, placed on the wire mesh floor of the room). When a particular source was placed onto the turntable, the height of the microphone and preamplifier (which were suspended from the ceiling) were adjusted until they were level with the centre of the noise producing area of the source under investigation. The microphone and preamplifier were not allowed to swing freely, but were secured by attaching a length of cord from them to the floor of the room. Once the source and turntable were switched on, the level recorder was triggered. The polar paper inserted in the level recorder moved synchronously with the turntable through 360^0. After rotating through 360^0, both the turntable and polar paper automatically stopped rotating. The noise output of the appliance was transmitted via the microphone and preamplifier to the measuring amplifier and band pass filter set and to the level recorder. For each appliance investigated, four directivity measurements were performed, and the results recorded as traces on the polar paper:

1. Directionality at 500 Hz (using the band pass filter set to filter out everything except 500 Hz band).

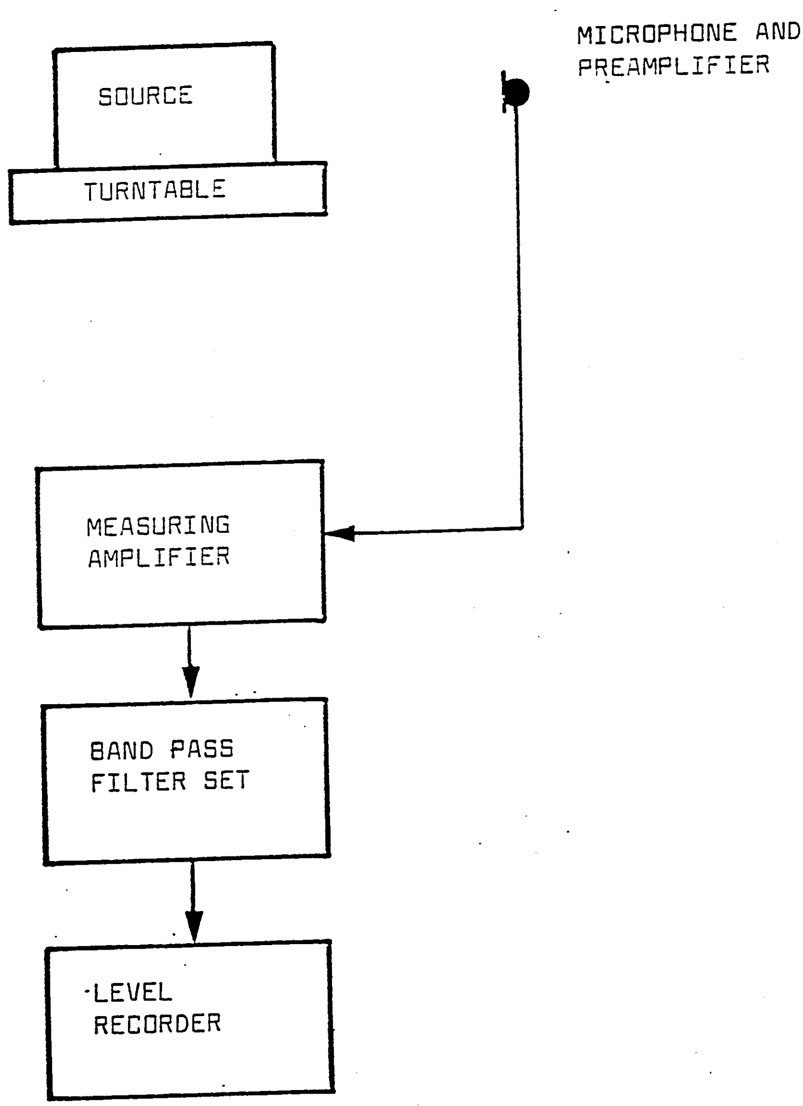


Figure 5.7 Equipment required for directionality measurements in an anechoic room.

2. Directionality at 1000 Hz.

3. Directionality at 2000 Hz.

4. Directionality in terms of overall A-weighted sound pressure level.

The results of these measurements (the polar plots) are presented in Appendix C. Examination of the polar plots for the tested appliances revealed that all, with the exception of the Kenwood Chef A901 food mixer, exhibited noise directional characteristics. The details are as follows:

1. Prestige L2001 food processor: the directional characteristics at 2 KHz were attributed to the noise emitted from the motor.

2. Philips HM3060 food mixer: the directional characteristics at 500 Hz were also attributed to the noise emitted from the motor.

3. Philips TX2000 Liquidiser: the directional characteristics at 500 Hz were attributed to the motor noise.

4. Hoover U2002 vacuum cleaner: the directional characteristics at 1 KHz were attributed to the noise emitted from the motor, which is situated at the rear of the vacuum cleaner (in the user position).

5. Electrolux ZA65 vacuum cleaner: the directional characteristics at 500 Hz and 2 KHz, were also attributed to the motor noise.

6. Braun 1200 Supercompact hair dryer: the directional characteristics at 500 Hz and 1KHz were attributed to the air intake section at the rear of the appliance.

7. Boots MD2 hair dryer: the directional characteristics at 2 KHz were attributed to the air intake section.

8. Clairol 1200 hair dryer: the directional characteristics at 1 KHz, were attributed to the air outlet section (due to a shaped nozzle that concentrated the air through small vents).

For the implications of the directional characteristics, consult Chapter 10, section 10.2. With the exception of the Kenwood Chef food mixer, it can be concluded that all the appliances tested exhibited noise directional characteristics.

5.1.13 Results

The A-weighted sound power levels obtained for the domestic appliances used in this study can be seen in Tables 5.4, 5.5, 5.6, 5.7 and 5.8. The appliances were obtained from staff of the Open University and colleagues, and were in good working order.

Table 5.4 A-weighted sound power levels (L_{WA}) of hair dryers, measured according to ISO 3741.

Appliance	L_{WA}
Boots MD2 Hair Dryer - Speed 1	69
Boots MD2 Hair Dryer - Speed 2	77
Moulinex 722 Beauty Styler Hair Dryer - Speed 1	71
Moulinex 722 Beauty Styler Hair Dryer - Speed 2	78
Ronson Hotshot Hair Dryer - Speed 1	73
Ronson Hotshot Hair Dryer - Speed 2	82
Braun Compact 1500 Hair Dryer - Speed 2	74
Braun Compact 1500 Hair Dryer - Speed 3	81
Braun Supercompact 1200 Hair Dryer - Speed 1	76
Braun Supercompact 1200 Hair Dryer - Speed 2	81
Clairol 1200 Hair Dryer - Speed 1	80

Table 5.5 A-weighted sound power levels (L_{WA}) of vacuum cleaners, measured according to ISO 3741.

Appliance	L_{WA}
Electrolux 520S Supersuction Vacuum Cleaner	77
Electrolux ZA65 Vacuum Cleaner	79
Electrolux 350E Vacuum Cleaner	79
Kerstar C606 Supreme Vacuum Cleaner	80
Electrolux 345 Automatic Vacuum Cleaner	80
Electrolux 350E Vacuum Cleaner - Superboost	82
Hoover U2002 Vacuum Cleaner	88
Hoover 119 Vacuum Cleaner	91

Table 5.6 A-weighted sound power levels (L_{WA}) of food mixers measured according to ISO 3741.

Appliance	L_{WA}
Philips HR1907 Food Mixer - Speed 1	68
Kenwood Mini A345 Food Mixer - Speed 2	74
Philips HM3060 Food Mixer - Speed 1	75
Kenwood Chef A901 Food Mixer - Speed 4	83

Table 5.7 A-weighted sound power levels (L_{WA}) of liquidisers measured according to ISO 3741.

Appliance	L_{WA}
Philips TX2000 Liquidiser - Speed 1	76
Moulinex 530 Liquidiser	82
Moulinex 241.2 Liquidiser	84
Kenwood Chef A901 Food Mixer plus Liquidiser - Speed 4	85

Table 5.8 A-weighted sound power levels (L_{WA}) of food processors, measured according to ISO 3741.

Appliance	L_{WA}
Prestige L2001 Food Processor	80
Robot Chef RC3 Food Processor	85
Braun MC-1Food Processor	87

A-weighted sound power levels for all appliances ranged from 68 to 91 dBA with over half the levels above 80 dBA.

5.1.14 Discussion of the Results

When the frequency spectra of the appliances were examined, it appeared that some of the appliances exhibit discrete frequencies/narrow bands in their spectra (For example, see Figure 5.8).

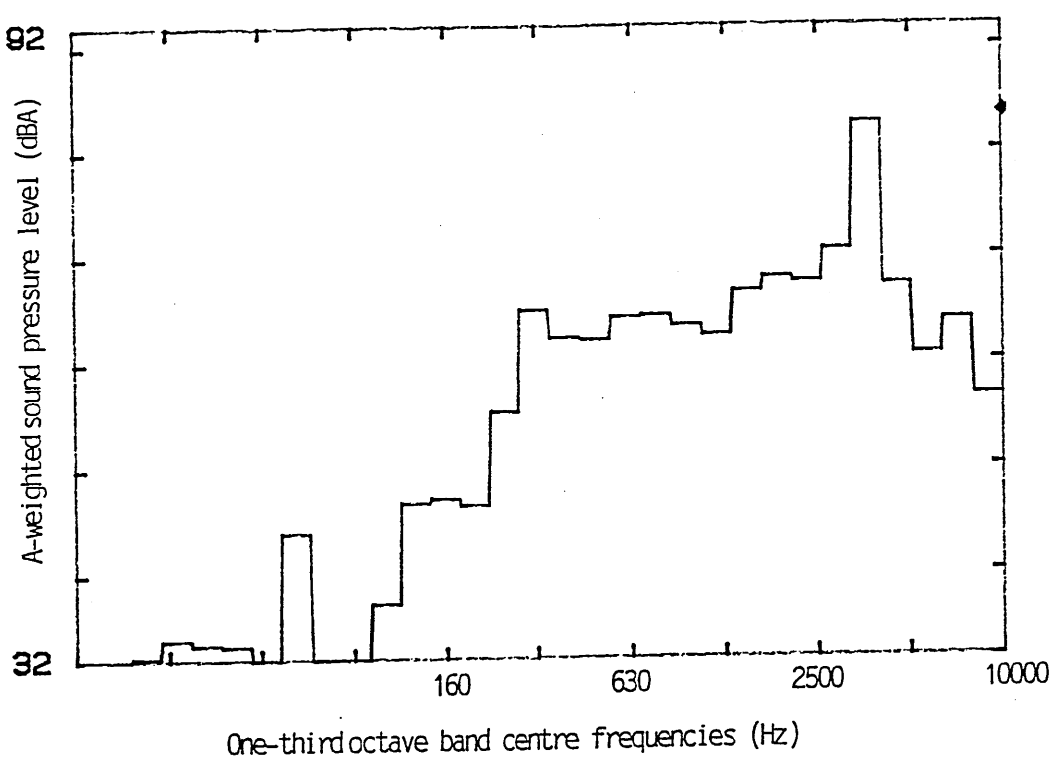


Figure 5.8 Time-averaged A-weighted sound pressure levels for each one-third octave centre frequency of Braun MC - 1 Food Processor.

According to ISO 3741:

> When discrete frequencies or narrow bands of noise are present in the spectrum of a source, the mean-square sound pressure tends to be highly dependent on the positions of the source and the microphone within the room. The average value over a lim-

ited microphone array may differ significantly from the value averaged over all points in the room.

In such cases it is recommended that measurements be carried out according to ISO 3742 - Precision methods for discrete-frequency and narrow band sources in reverberation rooms. The objective of this standard is to specify the special requirements that are necessary for accurate determination of the sound power when discrete frequencies or narrow bands of noise are radiated by the source. The field of application is for spectra which 'may or may not include broad-band components upon which the prominent discrete frequencies or narrow bands of noise are superposed.'

In ISO 3742 a formula is provided for determining the presence of discrete frequency components or narrow bands of noise in the spectrum of the sound emitted by the source. This formula allows one to estimate the standard deviation of the sound pressure levels produced by the source under test.

$$s = [n-1]^{\frac{-1}{2}} \left[\sum_{i=1}^{n} (L_i - L_m) \right]^{\frac{1}{2}} \tag{5.7}$$

where:

s is the standard deviation of space/time-averaged sound pressure levels in the room L_i, in decibels.

L_m is the arithmetic mean value of the sound pressure levels, L_1 to L_6, in decibels.

$n = 6$.

Then the value of s, in turn, determines the number of microphone and source locations required for an accurate measurement of sound power level. (See ISO 3742 for further details)

With the benefit of hindsight, and having the spectral information to study, it is felt that the A-weighted sound power levels obtained for the appliances might have been more accurately determined using ISO 3742 (which basically means using more microphone and source locations). This factor is important when comparisons are made between subjective ratings and A-weighted sound power level index - if some sound power levels are not accurate, and the correlation between A-weighted sound power level index and subjective ratings is poor (as is shown in Chapter 8, section 8.5) in comparison with other physical properties of the noise, then it could be argued that the sound power level index has not been given a fair representation. However, a decision was taken that the measurements would not be repeated, based on the following arguments:

- In Chapter 8 subjective ratings are compared with *A-weighted* sound power levels. Examination of the A-weighted sound power level spectra revealed that, of the appliances displaying discrete frequencies, in most cases they appear below 1 kHz. Therefore A-weighting will reduce the effect of the discrete frequencies, as it emphasizes high frequencies.

- It was decided that repeating the measurements was unlikely to improve the correlation coefficient of A-weighted sound power level index so that it would be comparable with values obtained for the other noise indices (for example for equivalent continuous A-weighted sound pressure level index $r = 0.882$). (See Chapter 8 for further results).

5.2 *In situ* measurements of domestic appliance noise

Measurements of A-weighted sound power level (accompanied by directivity measurements) describe the sound emission level of the appliance. However, in a subjective experiment subjects will respond to ***A-weighted sound pressure level*** which is dependent on the environment in which the appliance is used. In order to understand particular subjective responses to domestic appliance noise in a particular location, it is necessary to determine A-weighted sound pressure level of the appliances in that location. A series of subjective experiments were undertaken in Park Corner Cottage , (the test location for the subjective experiments - Chapter 6, section 6.2). At this location the following measurements were made:

1. A-weighted sound pressure level (L_{pA})
2. equivalent continuous A-weighted sound pressure level ($L_{Aeq,30sec}$)
3. maximum A-weighted sound pressure level emitted during operation of an appliance (L_{Amax})
4. single event noise exposure level (L_{AX})
5. tape recordings to obtain the frequency spectra of each appliance at the listener position
6. time histories of the appliances

Measurement of the time histories of the appliances took place in the absence of subjects, whereas the remaining measurements were made during the subjective experiments.

5.2.1 Measurements made during the subjective experiments

Measurements (1 - 5 in section 5.2) were conducted during the subjective experiments to ensure that objective noise level measurements could be directly compared with subjective responses to domestic appliance noise. During each subjective experiment recordings were made of the appliance noises. Two half inch microphones (Bruel and Kjaer Type 4165) were positioned behind the subjects, approximately at ear height. One microphone was connected via a Bruel and Kjaer microphone preamplifier Type 2639 to a Nagra IV-SJ tape recorder, (with A-weighted filter and slow averaging time selected). The second microphone was connected to a noise level analyzer (Bruel and Kjaer Type 4427). The microphones were calibrated at the start and finish of each experimental session, using a piston phone (Bruel and Kjaer Type 4230). The drifting occurring during the sessions was negligible. The analyzer and tape recorder were connected via a cable, to enable the noise level analyzer to trigger the tape recorder.

The analyzer was programmed to monitor single events. Basically, this means that when a predetermined noise level is exceeded (as dictated by the appliances under investigation at the time) for a predetermined time period (usually five seconds), the analyzer will measure:

- equivalent continuous A-weighted sound pressure level ($L_{Aeq,30sec}$)
- maximum A-weighted sound pressure level (L_{Amax})
- single event noise exposure level (L_{AX})
- and the duration of the event (whereby an event is defined as the presentation of each stimulus).

A function on the analyzer was selected for automatically starting a tape recorder when a predetermined level and predetermined time period is exceeded. By replaying the calibrated appliance noise recordings into an FFT analyser (Ono Sokki 910) and averaging the signal over 128 averages, it was possible to obtain time-averaged A-weighted sound pressure levels for each one-third octave centre frequency from 100 Hz to 10 kHz. These levels are presented in Appendix D for each appliance investigated, in tabular form. From the tape recordings the following indices were calculated:

1. A-weighted sound pressure level of the appliances - this will be referred to as L_{pAav} since it was calculated from time-averaged values.
2. D-weighted sound pressure level of the appliances. Again, this will be referred to as L_{pDav} since it was calculated from time-averaged values. This value was obtained by converting the A-weighted values to linear values and and adding or subtracting the appropriate D-weighting for each one-third octave centre frequency.
3. Sound pressure level of the appliances. This was calculated by first converting the A-weighted values to linear values. This index will be referred to as L_{pav} since the values are calculated from time-averaged values.

4. Perceived Noise Level (PNL), using the method described in Chapter 3, section 3.3.2. A-weighted one-third octave centre frequency values were converted to unweighted values before the calculation of PNL.

Sound pressure levels (unweighted, A and D-weighted) were calculated using the following formula [39]:

$$10\ log_{10} \sum 10^{\frac{L_i}{10}} \tag{5.8}$$

where L_i refers to the sound pressure level at each one-third octave centre frequency. Therefore, it was possible, not only to record the appliance noise levels as heard by the subjects, (and determine the average sound pressure level, average D-weighted sound pressure level and Perceived Noise Level for the appliances) but also to determine equivalent continuous A-weighted sound pressure level, A-weighted sound pressure level, single event noise exposure level, and the maximum A-weighted sound pressure level of the event. These indices were correlated with subjective ratings to appliance noise.

5.2.2 Results

The results obtained for each appliance can be seen in Tables 5.9, 5.10, 5.11, 5.12 and 5.13.

Table 5.9 *In situ* measurements for hair dryers.

Appliance	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	PNL	L_{pav}	L_{pDav}
Boots MD2 - Speed 1	65.5	61.3	62.9	75.7	80.4	66.7	74.7
Boots MD2 - Speed 2	70.9	68.2	73.3	83.6	85.2	71.6	79.2
Moulinex 722 - Speed 1	66.1	64.9	65.8	80.2	79.2	66.6	73.8
Moulinex 722 - Speed 2	75.1	71.7	73.0	86.9	88.3	74.8	83.5
Ronson Hotshot - Speed 1	69.3	67.9	68.8	83.2	80.7	69.9	74.9
Ronson Hotshot - Speed 2	75.4	74.1	75.0	88.9	89.3	75.1	83.4
Braun Compact 1500 - Speed 2	67.9	67.2	67.9	82.4	81.0	68.5	75.9
Braun Compact 1500 - Speed 3	75.3	72.7	73.2	87.5	88.7	74.8	83.8
Braun 1200 - Speed 1	68.1	69.6	70.6	84.6	80.8	68.2	75.1
Braun 1200 - Speed 2	75.8	74.1	74.7	89.0	89.0	75.5	83.5
Clairol 1200 - Speed 1	73.5	69.4	70.7	84.4	86.1	79.8	73.4

Table 5.10 *In situ* measurements for vacuum cleaners.

Appliance	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	PNL	L_{pav}	L_{pDav}
Electrolux 520S Supersuction	73.5	71.8	73.5	87.1	84.8	76.3	78.3
Electrolux ZA65	72.9	67.7	71.0	84.2	86.2	80.1	79.0
Electrolux 350E	69.7	69.9	71.5	85.3	82.7	76.6	75.9
Kerstar C606 Supreme	74.8	71.9	74.6	87.5	87.7	77.0	80.9
Electrolux 345 Automatic	75.8	71.2	72.4	86.9	89.1	81.3	82.1
Electrolux 350 E Superboost	72.2	74.0	75.7	89.3	86.1	79.9	78.7
Hoover U2002	82.7	82.7	84.0	98.1	94.8	89.6	87.4
Hoover 119	84.0	81.9	82.9	97.0	95.3	88.2	90.0

Table 5.11 *In situ* measurements for food mixers.

Appliance	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	PNL	L_{pav}	L_{pDav}
Philips HR1907 - Speed 1	68.0	66.7	67.8	81.9	81.6	72.4	75.4
Kenwood Mini A345 - Speed 2	70.6	66.3	67.4	81.6	87.7	74.8	81.3
Philips HM3060 - Speed 1	67.9	70.1	71.9	85.2	81.1	70.3	74.9
Kenwood Chef A901 - Speed 4	77.9	77.0	77.6	92.2	90.3	78.8	83.8

Table 5.12 *In situ* measurements for liquidisers.

Appliance	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	PNL	L_{pav}	L_{pDav}
Philips TX2000 - Speed 1	73.0	75.1	76.7	90.3	90.4	78.3	84.3
Moulinex 530	76.4	75.4	76.4	90.5	88.9	77.1	83.8
Moulinex 241.2	83.3	78.3	79.1	93.5	94.6	86.5	89.1
Kenwood Chef and Liq. - Sp 4	81.3	78.9	79.6	94.3	94.2	81.4	88.5

Table 5.13 *In situ* measurements for food processors.

Appliance	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	PNL	L_{pav}	L_{pDav}
Prestige L2001	69.3	69.4	71.1	84.6	81.5	70.4	74.6
Robot Chef RC3	80.5	79.0	80.0	94.3	93.8	80.2	89.2
Braun MC - 1	83.6	81.6	85.0	96.6	98.2	83.2	93.1

Table 5.14 demonstrates how the noise indices correlate with each other, using the format of a correlation matrix. (Tone corrections were made to Percieved Noise Levels to produce Tone Corrected Perceived Noise Levels (TPNL) according to BS 5727 [63]). It can be seen that the indices are highly correlated with each other. The problem associated with the indices being highly correlated with each other is that it will be difficult to assess which index correlates significantly better with noisiness ratings than another. However, the problem was overcome using the statistical technique of Bootstrapping (see Chapter 7, section 7.1.11).

Table 5.14 Correlation matrix for the noise indices investigated.

Index	L_{WA}	L_{Aeq}	L_{Amax}	L_{AX}	L_{pav}	L_{pDav}	L_{pAav}	PNL	TPNL
L_{WA}									
L_{Aeq}	0.911								
L_{Amax}	0.913	0.991							
L_{AX}	0.914	0.998	0.993						
L_{pav}	0.839	0.851	0.865	0.869					
L_{pDav}	0.823	0.881	0.876	0.876	0.826				
L_{pAav}	0.868	0.913	0.909	0.916	0.893	0.976			
PNL	0.850	0.893	0.896	0.893	0.882	0.989	0.984		
TPNL	0.844	0.867	0.870	0.866	0.854	0.983	0.980	0.985	

In attempting to establish if the appliances used in this study are typical examples of their genre, one can compare A-weighted sound pressure level data obtained in these experiments with data obtained by other researchers, as discussed in Chapter 2, section 2.2. Table 5.15 presents a comparison of the results. It should be remembered, however, that A-weighted sound pressure levels are determined by the environment in which the measurements are taken. Therefore it is only relevant to consider the overall range of values rather than the individual values.

Food processors were not investigated in the other studies cited. They are a relatively new type of appliance. The only available values for food processors are those taken from a private unpublished test report by a com-

Table 5.15 Comparison of A-weighted sound pressure levels for domestic appliances from several studies [7], [8], [11].

Appliance	Present study	1971 [7]	1975 [8]	1984 [11]
Hair Dryer	62 - 75	59 - 65	63 - 79	64 - 82
Vacuum Cleaner	68 - 85	62 - 85	67 - 83	67 - 84
Liquidiser	76 - 81	62 - 88	87 - 90	59 - 85
Food Mixer	66 - 77	49 - 79	58 - 85	64 - 86
Food Processors	69 - 82			

mercial test house (quoted in [107]). A-weighted sound pressure levels of five food processors were measured in a typical kitchen-size semi-reverberant room at the operators ear position, 1.5 m above the floor. The range of levels obtained during operation, on load, was 71 - 98 dBA.

It can be concluded that the appliances investigated in this study are typical examples of their genre in terms of the range of A-weighted sound pressure levels obtained during measurements in Park Corner Cottage.

5.2.3 Time Histories of Appliances

It is important to ascertain whether the noise level of any of the appliances varies with time, and the extent of this variation. This is particularly important in experiments designed to test whether the time factor is of importance (as in the case of Hypothesis 4, Chapter 4). If one examines Tables 5.9 5.10 5.11 5.12 5.13, it is possible to distinguish appliance levels which vary over time by comparing values of maximum A-weighted sound pressure level (L_{Amax}) and equivalent continuous A-weighted sound pressure level ($L_{Aeq,30sec}$). For an appliance level that does not vary with time, the values of maximum A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level will be very similar, as the sound energy output will remain steady. The criteria adopted for identifying appliances whose sound level varies with time is in cases where the difference between maximum A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level is greater than 2 dBA. Examination of the tables reveals five appliances for which the difference between maximum A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level and is greater than 2 dBA:

1. Boots MD2 - Speed 2
2. Electrolux ZA65 Vacuum Cleaner
3. Kerstar C606 Supreme Vacuum Cleaner
4. Prestige L2001 Food Processor
5. Braun MC - 1 Food Processor

Measurements of the noise emission over time were carried out using a half inch microphone capsule (Bruel and Kjaer Type 4165), a microphone preamplifier (Bruel and Kjaer Type 2639) connected to a noise level analyser (Bruel and Kjaer Type 4427). The microphone was positioned in the location of the subject's ear during the experiments, and approximately 1.5m away from the appliance. The analyser recorded the time history using a continuous print-out of noise level vs time (at a paper speed of 125mm/min). All the appliances were investigated and operated for approximately 30 seconds. The time histories for appliances displaying time varying characteristics are presented in Appendix E. The time history of the Braun 1200 Supercompact Hair Dryer is included for comparison, this being an appliance whose noise level did not vary significantly over time.

5.3 Summary of objective measurements and results

Using ISO 3741 A-weighted sound power level measurements were carried out on a selection of different types of appliances - namely hair dryers, vacuum cleaners, liquidisers, food mixers and food processors. A-weighted sound power levels ranged from 68 to 91 dBA, and were greater than 80 dBA for over half the appliances. The greatest levels were obtained for two Hoover vacuum cleaners and a Braun food processor. Directivity measurements were carried out on a selection of appliances and it was revealed that the appliances were directional around their motors and air intake/outlet areas.

In situ measurements in Park Corner Cottage were carried out to determine the following values for the appliances under investigation:

- A-weighted sound pressure levels
- equivalent continuous A-weighted sound pressure levels for 30 seconds
- maximum A-weighted sound pressure levels
- single event noise exposure levels.

A-weighted sound pressure levels ranged from 62 - 85, with the highest values obtained for a Hoover vacuum cleaner, a liquidiser and a food processor. These levels were compared with values obtained in other studies and it was concluded that the appliances were typical examples of their genre. Time history investigations revealed that a minority of appliance noise levels did vary with time, but for the majority of appliances, their noise emission levels were steady. This was also demonstrated by comparing values of maximum A-weighted sound pressure levels and equivalent continuous A-weighted sound pressure levels.

The objective measures of domestic appliance noise obtained in this Chapter will be correlated with subjective ratings of domestic appliance noise in an attempt to identify the factors contributing to a particular subjective reaction.

Chapter 6

Subjective ratings of domestic appliance noise

In designing the experiments to investigate the factors eliciting a subjective response to domestic appliance noise, there are a number of considerations to be made:

1. The conclusions drawn from an experiment must have precision. This is achieved by replicating or repeating some or all of the treatments. In these experiments each subject received each stimulus.

2. The conclusions drawn from an experiment must have validity. A valid experiment will be one that is planned so that the conclusions are free from the biases of the experimenter, and the way to eliminate biases is randomization of treatments.

3. The experimental conclusions must have wide coverage. To achieve wide coverage of results, a wide variety of subjects should be chosen, to represent different occupations, social group, ages etc. But the experimental variance will be smaller if the chosen subjects are more homogeneous (e.g. just females, or 20 year old subjects etc.)

These considerations are fundamental to the design of a good experiment. Each aspect of the experimental design will now be discussed.

6.1 Choice of Subjects

Subjects were randomly selected from among the staff and research students at the Open University. They were randomly selected from a number of different departments, occupational categories and ages. Both male and female subjects participated in the experiments and no subjects had been involved in noise assessment tests before. Ages ranged from 22 to 55 with a mean age of 32 (and a median age of 27 years old). A total of 32 subjects was required overall, but the actual number needed for each experiment depended on the particular experiment. There were two conditions imposed on the selection of subjects:

Normal Hearing

Subjects were required to have normal hearing (+/− 20 dB re ISO 389 - 1975 [108] in the range 0.25 to 8kHz). Each subject was tested for audiometric normality using a Madsen Electronic Memory Threshold Audiometer MTA86 calibrated regularly according to ISO 389. (It was owned by the local Occupational Health Clinic who ensure its regular calibration). Each subject was expected to undergo the test which was performed in a standard attenuating booth. Using the Automatic Threshold Program (described in Appendix F) subjects were presented with the following test sequence:

Left Ear (Hz) 1000 2000 1000 3000 4000 6000 8000 500 250 followed by
Right Ear (Hz) 1000 2000 3000 4000 6000 8000 500 250

The first tone is presented at a relatively high hearing level - 50 dB at 1000 Hz in the left ear. The subject responds by pressing the response button, and then the intensity is decreased in 10 dB steps until no response is made. The intensity is then increased by 5 dB until a response occurs. This is repeated until the program determines the threshold at that frequency, and then the next frequency is presented. One subject was eliminated from the experiments as a result of a hearing defect - the subject had severe hearing loss at 2, 3 and 4 kHz. Four subjects showed deficiencies at high frequencies - largely 6 and 8 kHz. Their thresholds were 40dB. They were not eliminated from the tests, however, because, most of the sound level energy of the domestic appliances investigated in this study was below 4 kHz. Losses at frequencies above 4 kHz were felt not to have a significant influence on their results.

As the subjective experiments took place over a period of 6 - 9 months, the audiometric test was repeated for a sample of subjects, particularly those who exhibited losses at high frequencies, to ensure that no major changes had occurred in the status of their hearing over this period. Sixteen subjects were re-tested and as expected, no change was detected.

Subjects were regular users of the appliances

Subjects were required to be regular users of the appliances. It was important that the appliances were not 'alien' to the subjects, as response to the noise level would then be difficult to assess. Although subjects were not regular users of the particular models of the appliances used in the experiment, they were regular users of that kind of appliance.

None of the subjects had previously participated in such an experiment so they were all alike in this respect.

6.2 Choice of Test Location

Although the choice of test location depends, to a certain extent, on the noise source under investigation, one has the choice of either an indoor or outdoor location. Many researchers use a specially designed listening room for subjective experiments as it permits examination of individual exposure to noise stimuli under controlled laboratory conditions. One such facility was built inside a large laboratory [88]. A couch was positioned in front of and facing the fireplace, and plush chairs, tables and lamps were positioned around the room. There were also wall accessories and drapes, and the floor was carpeted with a heavy duty, high density loop-pile carpet.

Other specially constructed listening rooms have been used extensively in subjective experiments ([94], [82], [84]).

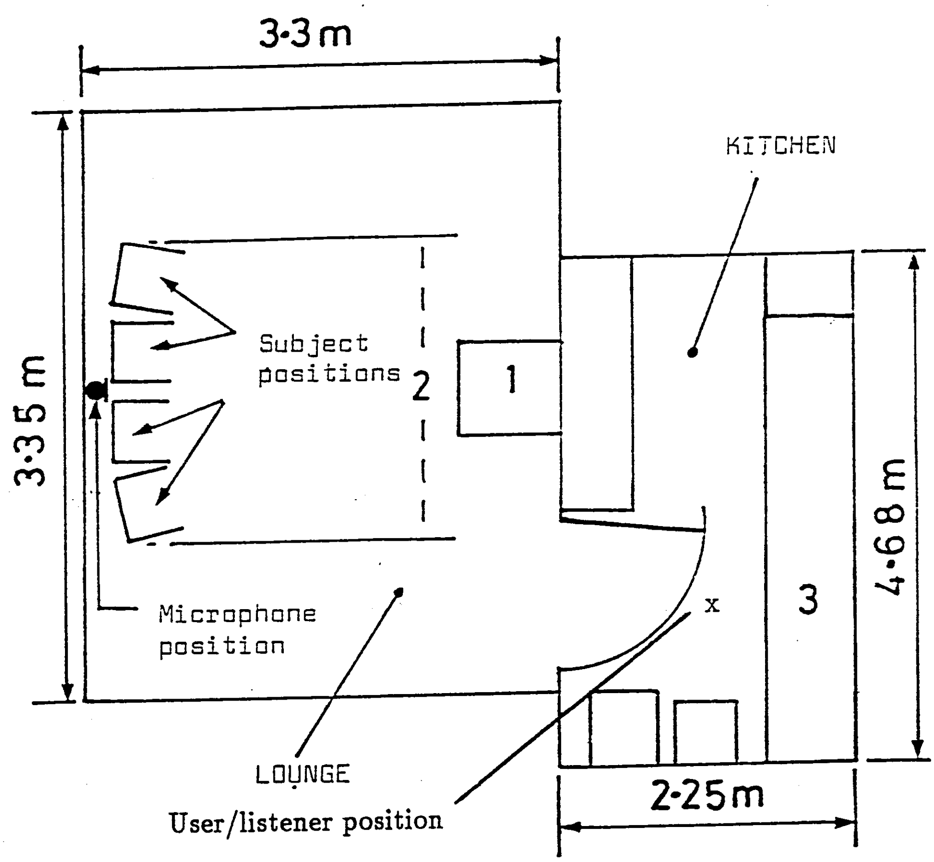
Listening rooms have been used to compare the results of laboratory experiments with results obtained outside the laboratory situation [86]. It has been suggested, however, that in the laboratory situation the subject is more aware of the controlled stimuli than s/he would be in his/her own home. So s/he is more likely to pay more attention to the stimuli, and his or her reactions may be slightly exaggerated.

In some research it has not been possible to use a specially designed listening room. A laboratory was used for the investigation of annoyance due to road traffic noise [87] [89]. Instead of attempting to simulate a living room, the laboratory was furnished as a student's study room.

In another study an outside location was more suitable. For example, in one study investigating subjective ratings of motor vehicle noise [72], vehicle pass-bys were felt to be more realistic than listening to recordings of motor vehicle noise inside a specially designed listening room.

The test rooms for the present study comprised the lounge and kitchen of a small detached house on the campus, which serves as temporary accommodation for visiting lecturers and newly appointed members of staff. It was considered preferable to use a 'real' lounge and kitchen rather than simulated versions of these rooms, so that subjective ratings would be given in 'natural' surroundings. Subjects should feel more relaxed in this test location, and thus it should be less difficult for them to imagine they were in their own home. The house was built in 1960 with standard cavity brick structure, and the dimensions of the rooms (including volumes and surface areas) can be seen in Figure 6.1.

Like many specially built listening rooms, the lounge and kitchen are decorated and furnished in a way that represented a 'normal' domestic living room and kitchen, although the furnishings were possibly sparser than one might expect to find in a typical domestic lounge. Because the rooms had not been specifically designed for experimental listening purposes, little was known about the acoustical characteristics of them. Therefore, reverberation times for both the lounge and kitchen were determined. (See Appendix G for methods and results). The main finding was that the re-



1 = Position of table top/hand held appliance
2 = Position of floor standing appliances
3 = Position of kitchen appliances in user/listener experiment

Room Details

LOUNGE:	Volume = 26.53 m^3	Surface area = 54.03 m^2
KITCHEN:	Volume = 14.06 m^3	Surface area = 29.27 m^2

Figure 6.1 Dimensions of the Test Rooms.

verberation times of the lounge (between 0.25 and 0.6 seconds depending on frequency) were slightly higher than that found in typical domestic living rooms (e.g. the average reverberation time for a British Living Room is in the range 0.27 to 0.38 seconds depending on the frequency [109].) The reason for this difference is attributed to the sparse room furnishings - thin carpet and curtains, office-type chairs instead of a sofa, no cushions, plants, pictures etc, typical of domestic living rooms. Thus the sound took longer to decay. The reverberation times of the kitchen were found to be 0.33 to 0.48 seconds depending on the frequency. The actual hypothesis under investigation dictated which of the rooms were used, and how many subjects were in the rooms at any one time (see section 6.9).

6.3 Mode of test stimuli - live or recorded?

In virtually all the experiments discussed in the previous section, whether the stimulus was aircraft noise or road traffic noise, the researchers chose to record the stimuli and play them back to subjects through loud speakers situated in the listening room. The exception to this was the use of vehicle pass-bys to maintain a realistic subjective evaluation of the stimuli in question [72]. It would seem that the choice of recorded or live stimuli depends on the individual researcher.

In previous research into subjective reactions to domestic appliance noise, recordings of the appliance noise have been used rather than the appliances themselves. No significant difference was observed between subjects' ratings when using the appliances and when replaying recordings of the appliance noise [32]. In two studies [33] and [32] recordings of the appliance noises were used because the concern was in correlating the subjective response to various noise level indices, rather than evaluating the non-acoustic factors that determine a particular subjective response. Therefore visual contact with the appliance was not considered very important.

In the present study, however, an appraisal of the usefulness of the appliances was required (this appraisal is not founded on the noise emission levels of the appliances), and so that the reactions be as natural as possible, the actual appliances were used rather than recordings.

Number of appliances to be used

Previous investigations of the subjective response to domestic appliance noise have been limited by the number of domestic appliances included in the study. For example two each of the following appliances were investigated in one study [32]: fan heater, food blender, tumble drier, washing machine and vacuum cleaner. Another study considered four washing machines and fan heaters [33]. Both cases studies recommended that a larger range of appliances, particularly families of appliances of the should be investigated in future experiments.

This recommendation was considered, and the following appliances were used for the subjective experiments in this study: six makes of hair drier (of which five were used at two different speeds), seven makes of vacuum cleaner (of which one was used with and without a super boost function), four makes of food mixer, four makes of liquidiser and three makes of food processor. The A-weighted sound power levels of these appliances were determined, as described in Chapter 5, section 5.1. The kitchen appliances were operated under a load consisting of a bread crumb and water slurry, as used in a previous study [8]. The remaining appliances were operated under normal use conditions, either by the experimenter or the participant.

6.4 Involvement of subjects in an activity

The involvement of subjects in an activity during the session, and the choice of the activity, varies considerably. In one study [94] the subjects were encouraged to read material of their choice. Subjects were encouraged to play cards during the experiments in another study [82] since card playing was an activity which had a high motivation level, can be easily played for long time periods, and was considered to be a relaxation activity which involved concentration and would not interfere with the subjective response.

Reading of text books of the subject's choice was encouraged in the experiments of [87] and [89]. In a further experiment [110], subjects were given a task to prevent them attending to the character or level of the noise, but rather to regard it as a background to this task. They were given the paper task of crossing out the letters 'p' and 'o', and the words 'his' and 'that', from a piece of text.

Where subjects did not partake in any activity their task was to rate the noise of the stimuli [33] [32] [72]. In the present study, subjects were asked to rate the noise of the appliances whilst they were listening to the noise. The exception to this was during the the experiments associated with Hypothesis 3, when subjects also rated the appliances after they had used them.

6.5 Method of randomizing stimuli

The randomization of stimuli is a very important aspect of experimental design as it helps to validate any conclusions drawn from an experiment. There are two designs that allow randomization of stimuli - randomized block design and Latin square design [111].

Randomized Block Design

When using randomized block design, the only process involved is that the stimuli symbols be arranged in random order in each block. The randomized block design is the simplest form of experimental design, making use of the idea of stratification. Stimuli are assigned to blocks and one replication of the stimulus is then applied in random order to each block. Any number of replications may be used. For example, with four stimuli, this procedure gives:

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1, 2, 3, 4    4, 1, 3, 2   1, 3, 4, 2 etc.
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Latin Square Design

With Latin square design, the grouping of replications occurs in two directions. Each stimulus occurs once in each row and once in each column, and the stimuli occur first equally often, second equally often, third equally often etc. Also used frequently is the balanced Latin square design whereby every stimulus follows every other stimulus an equal number of times. Table 6.1 shows the basic format of a balanced Latin square for four stimuli:

Table 6.1 Balanced Latin square design for four stimuli.

A	B	D	C
B	C	A	D
C	D	B	A
D	A	C	B

Stimuli are randomly assigned to a number, the numbers are randomly assigned to a letter and using the basic formula, the order of presentation of stimuli is determined. This is a balanced Latin square design.

Balanced Latin square design has several important features:

1. Grouping of replications of the stimuli occur in two directions so that each stimulus is heard once by each subject and occurs once in each presentation order. This minimises subject and presentation effects in the mean response for each appliance. (However presentation effects were found to be significant in some experiments - see Chapter 8, section 8.4.1).

2. As the mean response for each appliance is used, the effect on a subject's judgement of a noise due to noise immediately preceding it is minimized because of the balanced design - ie. each stimulus occurring once before each other.

3. Because each stimulus occurs once in each row and each column, row

(subject), column (presentation order) and stimuli effects each have their own sums of squares and the variation in subjective response due to these effects can be independently estimated. Due to sources of variation, one finds [112]:

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observed reaction = RE + CE + TE + RUV
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where:

RE = Row Effect

CE = Column Effect

TE = Treatment Effect

RUV = Random Unit Variation

Choosing the balanced Latin square design dictates the number of subjects required to complete a design. For any experiment, if the number of stimuli is n, and every subject is to do every condition, a Latin Square can be formed with n subjects - ie. the number of subjects is equal to the number of conditions. If one wanted to use more than n subjects, then one must chose some multiple of n. For example 2 x n or 3 x n subjects; otherwise each of the n possible orders can not be run an equal number of times. [112]

The balanced Latin square design is frequently chosen by researchers investigating subjective reactions to a variety of noises e.g. domestic appliance noise [33] and [32], annoyance due to impulse noise [84]. A more elaborate design has also been used which is termed a balanced Graeco Latin square (where both Latin and Greek letters occur once in each row and once in each column, and each Latin letter occurs once with each Greek letter). This was used to aid the laboratory study of nuisance due to traffic noise in a speech environment [96] and to determine judgements of aircraft noise (of 3 flyover modes and 3 levels) in a traffic noise background [83].

In the study of the relative annoyance of simulated sonic bangs and aircraft noise [58], the order of presentation of sounds was randomized although little detail of the form of randomization is given, other than that the first sound was always a reference which was used as a basis for annoyance comparison. A randomized design was also used in the outdoor investigation of the subjective rating of motor vehicle noise [72]. The order in which the 'vehicle-conditions' were presented to the observers was randomized 'within the limitation that no-one could undertake consecutive runs in opposite directions'.

In summary, there are two methods generally used in subjective experiments, that allow for randomization of the test stimuli and help to verify the conclusions drawn from the experiment. These are: randomized block design, an experimental design, making use of the idea of stratification (in one direction); and balanced Latin square design, allowing each stimulus to occur once in each row and column thus minimizing subject and presentation effects. Both methods have been used successfully in subjective experiments, so it was decided to randomize stimuli according to a balanced Latin square design, because of its simplicity and relative ease of analysis.

6.6 Choice of Rating Scale

In deciding upon the rating scale to be used during the subjective experiments (as discussed in Chapter 3, section 3.3), consideration was made of the following points:

- Using too short a scale could result in coarse ratings
- Using too long a scale would exceed the discriminating powers available to the subject.

The research by Parsons [33] suggested that different rating scales should be used according to the different domestic appliances investigated. For appliances of low sound levels, for example refrigerators or heating systems, the assessment of noise level should be carried out using a 4, or at most, 5 point scale. However, for appliances of a higher sound level, assessment should be made using a 7 or 10 point scale. The most obvious disadvantage with this suggestion is that the results of the two rating scales could not be directly compared as the scales are of different lengths.

To avoid a scale too long or too short, and the problems associated with these scales, it was decided that a 7 point scale be adopted in the present study, with the extremes labelled 'Very Quiet' (1) to 'Extremely Noisy' (7). It was decided to use 'Very Quiet' instead of 'not noisy at all' so as not to penalize subjects who might rate the appliances as being quiet. 'Not noisy at all' may not suggest that an appliance is quiet, only that it is not noisy.

The rating scale appeared in the questionnaire completed by subjects after the presentation of each appliance. For the sake of convenience, this questionnaire was termed a 'response sheet' in order to avoid confusing subjects when the time came for them to complete the more detailed questionnaires. The wording of the response sheets, (see Appendix H), completed by subjects during the experiments, was carefully chosen to ensure the instructions were concise and that subject biasing was not introduced. Subjects were required to rate each sound immediately after it had finished, thus subjects were making absolute judgements of each sound and not using the comparison method as discussed in Chapter 3, section 3.3.

6.7 Questionnaire Construction

Two questionnaires were constructed to obtain the information needed to test the hypotheses described in Chapter 4. Specific information was required regarding ratings of usefulness and the acceptability of appliances, and personal characteristics of subjects that might have some influence on a particular rating.

In designing the questionnaire a number of well-established guidelines were considered [113]. The first step in the design of a questionnaire is to state, in a concise way, the problem to be tackled by the survey, and thus to decide upon what questions to ask. One of the temptations facing researchers is to ask too much and devise a long and boring questionnaire. The length of the questionnaire is quite important, and must be presumed to affect the morale of the respondents, and thus the quality of the data. Every question must therefore be carefully considered for its relevance. Thus a pilot survey is necessary, as it identifies ambiguous questions and problems regarding the length of the questionnaire.

It is most important that the questions should be easily understood. If a question is not understood, it is likely to make the respondent feel uncomfortable. If certain factual responses are required, then the question should be so worded as to generate these facts. When opinions are required, then it is important either to:

1. ask the respondent how far they agree with a stated opinion, or

2. supply the answers to a set of questions about opinions into some sort of score (known as attitude scaling).

In both cases structured answers are required which could introduce the biasing of subject responses. There are simple rules to be followed regarding the wording of questions, as highlighted in textbooks about survey design [113]:

1. Avoid questions that are insufficiently specific.

2. Use simple language.

3. Avoid ambiguous questions - an ambiguous word will relay a different meaning to different subjects.

4. Avoid using vague words eg. 'generally', 'often', 'may', 'on the whole' (unless associated with attitude questions).

5. Avoid leading questions.

6. Avoid presumptive questions.

7. Avoid hypothetical questions.

Finally, question order is quite important - a simple question at the start of the questionnaire will help put the respondent at ease.

The importance of good wording and leading questions was highlighted [114] in a study to assess the bias in surveys of symptoms associated with noise. Comparisons were made of the reports of symptoms elicited by 2 different questions - one question did not mention noise, and in an alternative question symptoms were explicitly attributed to a noise source. The two questions - neutral and noise loaded - were asked of the same sample at different points in the same interview by the same interviewer. The order of questioning was altered so that half of the sample answered the neutral question before the other and half did the reverse. Positive correlations between symptoms and noise exposure may have been exaggerated due to bias arising from the way in which the question was worded.

Bearing these guidelines in mind, 2 questionnaires were constructed:

- one to determine the subject's noise sensitivity, feelings about their domestic appliances and personal details about the subjects
- the other to investigate ratings of usefulness, annoyance and acceptability relating to each of the appliances used in the experiment.

6.7.1 Questionnaire 1

This questionnaire (see Appendix I) can be subdivided into several sections:

- Section 1 - which included questions 1a to 1g, was designed to identify people's attitudes to domestic appliances, and more specifically, to identify whether respondents felt the domestic appliance noise levels were a cause of disturbance or nuisance. A 7 point category scale was used to determine subjects' willingness to put up with the noise of four frequently used appliances (1e). The extremes were labelled 'not willing' to 'very willing'. A similar scale was used to determine how noisy respondents felt their four chosen appliances were, with the extremes labelled 'very quiet' to 'extremely noisy'.
- Section 2 - these questions aimed to identify subjects' attitudes and usage patterns of four of the appliances used throughout the subjective experiments - hair dryer, vacuum cleaner, liquidiser, and food

mixer/processor. Usefulness was assessed on a 4 point category scale, where all points were labelled: very useful, useful, quite useful and not useful; similar to the commonly used annoyance scales [115]. Ratings of noisiness were again made using a 7 point category scale with the extremes labelled 'very quiet' and 'extremely noisy'.

- Section 3 - these questions aimed to investigate if subjects participated in any noisy activities that might influence their ratings, and also the amount of time spent inside the home, in an attempt to calculate the potential average noise exposure from domestic appliances.
- Section 4 - these questions aimed to identify individual sensitivity to noise in general and have been used regularly and successfully in noise surveys. They originate from the questionnaire, used in the survey of aircraft annoyance around London (Heathrow) Airport in 1961 [55].
- Section 5 - the classification questions were included to obtain the personal information about subjects that might influence their subjective reactions - for example age, sex, type of dwelling etc.

Details regarding the results of this questionnaire are presented in Appendix I. A pilot survey to test the questionnaire was carried out using 30 volunteers. As a result of the pilot survey a number of minor modifications were made to the questionnaire, largely modifications of the wording.

6.7.2 Questionnaire 2

This was a very simple questionnaire, composed of just 3 questions (see Appendix J):

A: to determine appraisals of usefulness of an appliance

B: to determine ratings of annoyance felt towards an appliance noise, and the reasons for this annoyance

C: to determine whether the noise of a particular appliance was considered acceptable in the subject's own home.

For questions A and B, 4 point labelled category scaling was used. For question C, a simple 'yes' 'no' response was required. The questionnaire was completed for each of the appliances included in the experiment - one questionnaire covered 6 appliances. The results of this questionnaire are discussed in Chapter 8, in conjunction with hypothesis testing (Hypotheses 9 - 14).

6.8 Design of the Instruction Sheet

In order to obtain consistent results, it is important that subjects receive a clear explanation of what is required of them. A particularly important consideration is the way in which any instructional material is chosen. It is important that there is nothing idiosyncratic about the words or sentences used in an experiment, as they might introduce effects which are irrelevant to the main purpose of the experiment. Therefore, in the written instructions (see Appendix K), the words were carefully chosen, and there were no verbal instructions beyond emphasis of the written material. Note that subjects were requested not to look at their neighbour's response, in order that the results obtained would, to all intents and purposes, be independent.

6.9 Experimental Procedure

After completion of a successful audiometry test, each subject was assigned at random to a particular experimental session (the number of sessions being dictated by the Latin square design - see Appendix L for the Latin squares associated with each experiment). Thirty two subjects were used to test hypotheses 1 - 4 and 24 to test the remaining hypotheses. On arrival at the experimental location, the subjects, (usually in groups of four, sometimes two), were requested to sit down and read the instruction sheet attached to a clip board given to each participating subject. They were then asked to fill in the personal details at the top of the response sheets and the experiment began.

Each stimulus was presented, one at a time, for thirty seconds, and subjects were asked to rate the noisiness of each stimulus, (after it had been switched off), on the response sheet. This sheet was then taken from the subjects (to prevent Session A ratings to influencing Session B ratings) and they were requested to complete the questionnaire (Questionnaire 1). The time taken to complete the questionnaire (approximately fifteen minutes) gave subjects the opportunity of acclimatising themselves to the quiet ambient noise level. On completion of the questionnaire, the appliances were presented to subjects a second time, but in a reversed order, as dictated by the Latin square design. The same procedure of rating was followed, after which subjects were thanked for their co-operation and they left the test location. The duration of the test was usually about twenty minutes. During each session, measurements of the appliance noise level were made (as discussed in Chapter 5, section 5.2). Deviations from this basic procedure occurred when different hypotheses were investigated.

6.9.1 Testing of Hypothesis 3 - relationship between user and listener noisiness ratings

To test this hypothesis 32 subjects were required to rate the appliances under two conditions: when listening to the appliance and also when using the appliance. This required the completion of two response sheets - one while the subject was using the appliances, and one while the subject was listening to the appliances (see Appendix H). The listener stood approximately 1m away from the appliances used in the kitchen, and was seated in the lounge while the vacuum cleaner and hair dryer were operated, 1.5m in front of him/her. The difference in noise level between user and listener positions was small (see Table 6.2).

A set of notes was issued to the subject using each appliance (see Appendix K). Only two subjects could participate at any one time - one acting as user, one as listener, and then the roles were reversed. A food processor and liquidiser were used and listened to in the kitchen and a hair dryer and vacuum cleaner were used and listened to in the lounge, in an attempt

Table 6.2 A-weighted sound pressure levels (L_{pA}) in user and listener positions.

Appliance	User Position	Listener Position
Vacuum Cleaner	83.3	82.7
Food Processor	91.5	90.2
Liquidiser	82.0	80.3
Hair Dryer	70.9	68.6

to simulate normal-use conditions. However, remaining experiments took place only in the lounge (for the sake of convenience, and to prevent the distraction of subject's attention while the experimenter moved back and forth between rooms to use the various appliances.)

In order to obtain the sound levels at the users and listeners ears, it was necessary for a sound level meter to be used. A CEL 393 Precision Computing Sound Level Meter was used. Like a noise level analyzer, it can analyse specific noise events. A predetermined noise level is set, and the sound level meter will register single event noise exposure level, maximum A-weighted sound pressure level and the duration of the event. The equivalent continuous A-weighted sound pressure level can be calculated from the following formula:

$$L_{AX} = L_{Aeq} + 10\, logT \tag{6.1}$$

The subject was carefully instructed on the positioning of the sound level meter during use of the appliances to ensure measurements were made as close to ear level as was possible during operation of each appliance. This was to enable the assessment of noisiness to be related to the level actually heard at the ear of the subject, and not at the operating position of the appliance. The appliances could be used quite normally with one hand, while the sound level meter was held in the other hand at ear level. When all the appliances had been used by a subject, the subject was requested to pass the sound level meter to the experimenter where the event data was read from it. Subjects were not required to complete a questionnaire, and the session lasted approximately fifteen minutes.

6.9.2 Testing of Hypothesis 4 - relationship between length of exposure and noisiness ratings

To investigate this hypothesis, it was necessary to vary the time of operation of the appliances. The appliances were operated, for fifteen seconds in the first session, and then in the second session for thirty seconds, in a reversed order. There were four appliances used - a hair dryer, a vacuum cleaner, a food processor and a liquidiser. The timings chosen for this experiment were dictated by the operating requirements of the appliances themselves, especially the kitchen appliances. Usually, kitchen appliances such as food processors and liquidisers are not used for long continuous durations, but are operated in short bursts. Thirty seconds was considered to be the maximum time that the kitchen appliances could be operated without damage to the motors of these appliances. With the exception of the time factor, the basic experimental procedure, as outlined previously, was followed. Thirty two subjects completed this experiment (which did not require a questionnaire) and each session lasted approximately ten minutes. The experiment was repeated, reversing the order of the durations.

6.9.3 Testing of Hypothesis 5 - to determine the relationship between A-weighted sound power level and noisiness ratings

Examination of this hypothesis is based on a series of five separate experiments, using six different appliances for each experiment. The results of these experiments generated the data for the investigation of the remaining hypotheses (5 - 14). One of the most important considerations of this series of experiments was that appliances be grouped in such a way that enabled appliances of similar A-weighted sound power level to appear together. Tables 6.3, 6.4, 6.5, 6.6,and 6.7 show the groupings used. The availability of appliances at any one time meant that appliances were used in the following order: Group 3, 2, 1, 4, and 5.

Table 6.3 Group 1 Appliances.

Appliance	L_{WA}
1. Boots MD2 Hair Dryer - Speed 1	69
2. Philips HR1907 Food Mixer - Speed 1	69
3. Moulinex 722 Beauty Styler Hair Dryer - Speed 1	71
4. Ronson Hotshot Hair Dryer - Speed 1	73
5. Braun 1500 Compact Hair Dryer - Speed 2	74
6. Kenwood Mini A345Food Mixer - Speed 2	74

Table 6.4 Group 2 Appliances.

Appliance	L_{WA}
1. Electrolux 520S Vacuum Cleaner	77
2. Braun 1200 Supercompact Hair Dryer - Speed 1	76
3. Philips HM3060 Food Mixer - Speed 1	75
4. Philips TX2000 Liquidiser - Speed 1	76
5. Moulinex 722 Beauty Styler Hair Dryer - Speed 2	78
6. Boot MD2 Hair Dryer - Speed 2	77

Table 6.5 Group 3 Appliances.

Appliance	L_{WA}
1. Electrolux ZA65 Vacuum Cleaner	79
2. Prestige L2001 Food Processor	80
3. Electrolux 350E Vacuum Cleaner	79
4. Kerstar C606 Supreme Vacuum Cleaner	80
5. Clairol 1200 Hair Dryer - Speed 1	80
6. Electrolux 345 Vacuum Cleaner	80

Table 6.6 Group 4 Appliances.

Appliance	L_{WA}
1. Kenwood Chef A901 Food Mixer - Speed 4	83
2. Electrolux 350E Vacuum Cleaner - Superboost	82
3. Moulinex 530 Liquidiser	82
4. Braun 1200 Supercompact Hair Dryer - Speed 2	81
5. Ronson Hotshot Hair Dryer - Speed 2	82
6. Braun 1500 Compact Hair Dryer - Speed 3	81

Table 6.7 Group 5 Appliances.

Appliance	L_{WA}
1. Kenwood Chef A901 and Liquidiser - Speed 4	85
2. Hoover 119 Vacuum Cleaner	91
3. Moulinex 241.1 Liquidiser	84
4. Braun MC-1 Food Processor	87
5. Hoover U2002 Vacuum Cleaner	88
6. Robot Chef RC3Food Processor	85

Four subjects attended each session, and twenty four subjects participated. Subjects were required to complete a questionnaire in this experiment (Questionnaire 2) to obtain information about subjects' ratings of annoyance and acceptability, and appraisals of usefulness. Because of the nature of the questions asked in this questionnaire, it was completed at the end of session B, for each of the five experiments. Completion of the questionnaire in the period between session A and session B could have influenced subject's ratings in session B as subjects were made aware of factors such as annoyance by the questionnaire.

With these exceptions, the basic experimental procedure was adopted and the session lasted approximately twenty minutes.

6.9.4 Discussion

As there were limited numbers of appliances that had identical sound power levels, restrictions were placed on the appliance groupings. This restricted the experiments in that the range of sound power levels in each group was generally quite limited (at most 6 dBA). When the data was analysed (see Section 8.5) it was apparent that the ratings reflected this. The range of scale sensitivity is clearly reduced until sound power levels become higher. Only then is the scale sensitivity truly apparent. (See Chapter 10, Section 10.2 for suggested experimental design improvements to overcome this problem).

6.9.5 Summary

The experimental procedure involved the presentation of appliance noises to subjects, in an order defined by the balanced Latin square design. Subjects rated the appliances along a scale of noisiness ranging from 'Very Quiet' to (1) to 'Extremely Noisy' (7). Then the presentation of appliances to subjects was repeated, but in reversed order, and subjects were requested to rate the appliances again. Depending on the hypothesis under test, subjects were required to complete a questionnaire, either in between sessions, or at the end of the experiment. Deviations from this procedure depended on the hypothesis under investigation e.g. hypothesis 5 required the use of six appliances, grouped according to A-weighted sound power level, and completion of a questionnaire at the end of the experiment.

6.10 Summary of subjective rating experiments

1. The subjects that participated in the experiments were randomly selected from among the staff and research students of the Open University. The mean age was 32 years old. Subjects were required to have normal hearing, and be regular users of the appliances.

2. The lounge and kitchen of a cottage on University campus were chosen for the test location. The reverberation times measured were slightly longer than typical, and this was attributed to the sparse furnishings of the cottage.

3. The appliances themselves were used, rather than recordings as appraisals of non-acoustic factors were being evaluated (appraisals of usefulness) and it was important that they were given under natural circumstances (or as natural as was possible).

4. Subjects were asked to rate the noisiness of appliances during the experiment. With the exception of the experiment to test hypothesis 3 (differences between user/listener ratings) subjects were not involved in any activity.

5. The stimuli were randomized according to a balanced Latin square design, because of its simplicity and relative ease of analysis.

6. Subjects were required to rate the noisiness of domestic appliances according to a 7 point scale, where the extremes were labelled 'Very Quiet' (1) to 'Extremely Noisy' (7).

7. Completion of two questionnaires was required during the different experiments: one was designed to investigate subject's feelings about domestic appliances, their sensitivity and to classify subjects. The

other was designed to evaluate subjects' ratings of annoyance and acceptability of appliance noises, and appraisals of usefulness.

8. Instruction sheets were carefully worded to avoid subject bias. There were no verbal instructions beyond emphasis of the written material.

9. The experimental procedure involved presenting the appliances to subjects in an order determined by the balanced Latin square design, asking subjects to rate the noisiness of appliances, and then repeating the presentation to subjects in a reversed order. Deviations from this procedure depended on the hypothesis under investigation.

The analysis of the results of these subjective experiments, and the objective experiments are presented in Chapter 8.

Chapter 7

Analysis Methods

7.1 Introduction

The choice of appropriate statistical techniques to test the research hypotheses is very important, as it influences the credibility of conclusions that one can draw from an experiment. The selection of a suitable statistical test is influenced by the type of data generated from the experiment. Generally speaking there are two types of statistical tests:

- Parametric tests - a parametric test is one used to analyse the interaction between 2 or more variables when:

  1. the experimental scores are measured on at least an interval scale
  2. the scores are normally distributed
  3. there is homogeneity of variance between scores in the experimental condition.

  e.g Analysis of variance, t-test.

- Non-parametric tests - a non-parametric test is used to investigate the effects of single variables indirectly (e.g. by rank ordering the data) and when the experimental data do not meet the three assumptions of parametric test. e.g. Spearman Rank Correlation.

A variety of statistical techniques were adopted to test the hypotheses described in Chapter 4, using the statistical packages Minitab and SPSSX.

Each technique will be described, along with a discussion regarding the justification for choosing each technique.

7.1.1 Analysis of Variance

The purpose of the analysis of variance test is to partition the total variation in the data into components due to various causes, such as noise effects and differences between subjects, and a component not attributable to any individual cause - a residual component (or error component). An F ratio test may be used to test whether a component due to a particular cause contributes significantly to the total variation. The test is carried out by calculating the ratio of the variance due to the components and the residual variance. Analysis of variance also allows the examination of interactions between variables, as the interactions reveal relationships that might otherwise be ignored if one concentrates on the main variables alone.

Analysis of variance, like all parametric tests, has several strong assumptions underlying its use, but if the assumptions hold true for the model, then this test is extremely powerful. The following requirements (regarding the individual observations in an experiment) must be satisfied when using analysis of variance:

1. The observations must distribute themselves normally.
2. The observations must show the same degree of variability from treatment population to treatment population.
3. The observations must be independent from one another.
4. The data must show interval properties, so that it is possible to use the operation of arithmetic on the scores.
5. Additivity of components must exist.

The importance of these requirements and the extent to which each requirement has been met by the data and conditions of this research are discussed in the following sections.

The observations must distribute themselves normally.

There exists a school of thought which states that this condition is not strictly essential for analysis of variance to be used. The view of statistical theorists [116] is that repeated observations that differ because of experimental error often vary about some central value in a roughly symmetric distribution in which small deviations occur more frequently than large ones (the normal distribution). According to the Central Limit Theorem, under certain conditions, usually met in the 'real world of experimentation', these distributions will tend to normality as the number of components become large, almost irrespective of the individual distributions of the components. (See Appendix M for an illustration of this phenomenon). So the sample average tends to be normally distributed, even though the individual observations on which it is based are not. Thus statistical methods that depend, not directly on the distribution of individual observations, but on the distribution of one or more averages of observations, tend to be insensitive or robust to normality.

This argument is endorsed by research methodologists [117] who also argue that analysis of variance is robust with respect to the normality assumption; that the data do not have to meet it exactly, or even closely if the data is plentiful, with many cases in each group. After discussion with an Open University statistician, it was agreed that the data obtained by the subjective experiments in this research is considered an adequate amount to satisfy this assumption.

The observations must show the same degree of variability from treatment population to treatment population.

This assumption is also referred to as homogeneity of variance, and according to some statisticians, it is the most crucial condition for analysis of variance.

Homogeneity of variance suggests constant variance across all treatment groups. One method to test for homogeneity of variance is to compare the maximum variance (of the residuals) to the minimum variance, across treatment groups. (A residual value is the difference between the observed value and the fitted value). By looking in the appropriate statistical table (see Appendix N) one can identify cases where the ratio between the maximum and minimum variance is significant, and thus where constant variance across treatment groups is not observed. This test was performed on all treatment groups (with the exception of subjects, as comparisons between subjects were not as important in this study). The results can be seen in Appendix O where there is evidence of constant variance across treatment groups, thus satisfying the assumption of homogeneity of variance. (This is just one way of testing for homogeneity of variance.)

Some researchers feel that it is not crucial to have homogeneity of variance. According to Erickson and Nosanchuk [117], homogeneity of variance is not a great concern if the groups are approximately equal in size. If they are (which they were in these experiments), the variance can be moderately unequal without disturbing the analysis of variance test. When discussing normality and homogeneity of variance assumptions, some theorists state that these are frequently not satisfied, particularly in psychological experimentation [118]. It appears that even relatively severe deviations from the assumptions have little effect on the evaluation process for researchers using randomized experimental design.

The observations must be independent from one another.

This implies that each rating is a separate piece of information, not affected by the others, and the score which is assigned to any case must not bias the score which is assigned to any other case. In considering the experimental design (see Chapter 6, section 6.8), it will be remembered that:

- Subjects were requested not to confer or to look at the responses from other subjects.
- Subjects were required to make an absolute judgement of the noisiness of the appliances and were not asked to compare one noise with another.

So, in theory, the observations may be regarded as independent. However, in practice, it is possible that, for some subjects, the score assigned to the first noise may well affect the score assigned to subsequent noises. But this fact can be disregarded for the following reasons:

- Because of the adopted Latin square design, for each group of subjects the order of presentation of appliances was changed.
- Because the mean score for each appliance is used, this effect may be assumed to cancel out.

Thus it is felt that the condition of independence of observations has been fulfilled.

The data must show interval properties, so that it is possible to use the operation of arithmetic on the scores.

Analysis of variance requires that the data be treated as numbers with equal intervals. This implies that the scores from an experiment must be measured on at least an interval scale. Strictly speaking, this means that analysis of variance should only be used when the measures are 'naturally' numerical. The data resulting from these experiments shows order properties, and not interval properties, whereby, on a scale of 1 to 7, very quiet to extremely noisy, 2 is not necessarily worse than 1, in the same degree that 5 is worse than 4. However, investigations have shown [117] that ordinal data can be treated like interval data quite safely, if the data have:

1. a fairly smooth distribution
2. if N is 'fairly large'
3. if the test is robust

The data resulting from these experiments has been examined by an Open University Statistician, and it is felt that this condition has been satisfied.

Additivity of components must exist.

According to one psychologist [119] researchers do not appear to question this assumption of additivity - namely that a mean score is made up of three parts:

1. a part representing average performance in the overall population
2. a part reflecting the treatment effect
3. a part reflecting experimental error.

Thus it is little mentioned in statistics text books and little importance is attributed to it. There is no reason to suppose that it is not satisfied in these experiments.

Summary of applicability of Analysis of Variance

In summing up the justification for use of analysis of variance test, the following points can be made. It is known that the underlying model:

mean= linear combination of effects due to subjects, order, appliances, sessions and interactions

is not quite accurate as it suggests a range of scores from zero to infinity. The model does not restrict scores to 1, 2, 3 etc (numbers that are integers) and it does not restrict scores to a range of 1 to 7. The model is approximate, but it is not contradicted dramatically by the data. For the most crucial assumption underlying analysis of variance, the assumption of homogeneity of variance, diagnostic tests were carried out that did not invalidate the assumption. So since all the assumptions related to the use of analysis of variance were either demonstrated to hold, or were considered reasonably satisfied, statistical analysis was carried out on the data using analysis of variance.

7.1.2 Post-hoc Comparisons

The variance-ratio test in the analysis of variance provides an overall test of the differences between a series of treatments. If the variance ratio is not significant, then only independent comparisons, decided before the start of the experiment, should be made. No other comparisons are valid.

However, if the variance ratio is significant it may be concluded that the treatment means differ significantly. It is then interesting to determine which treatment means differ from which. This is known as making post-hoc comparisons. The main problem with post-hoc comparisons is that the more comparisons that are conducted, the more Type I errors are likely to be committed. (This is when the null hypothesis is rejected in favour of the alternative hypothesis, when in fact the null hypothesis should not be rejected.) Two types of post-hoc comparisons will be discussed.

Least Significant Difference (LSD)

One method of determining which treatment means differ from which is the test known as Least Significant Difference (LSD) test. It requires that the null hypothesis be rejected, and consists of carrying out pair-wise comparisons on the treatment means. It is measured in standard error units. The standard error of the difference between pairs of treatment means (SE_{diff}) can be calculated using information in the analysis of variance table. The variance (s^2) of an individual cell mean is determined by:

$$s^2 = \frac{sum\ of\ squares\ of\ residual\ error}{degrees\ of\ freedom \times no.\ of\ cases} \times number\ of\ means \qquad (7.1)$$

The variance of the difference between any two means $= s_1^2 + s_2^2$. Then

$$(SE_{diff}) = \sqrt{s_1^2 + s_2^2}$$

Then:

$$LSD = 2 \times (SE_{diff})$$

where $p<.05$. There is a significant difference between two means if the difference exceeds the value of LSD.

This test is used throughout the hypothesis testing, when significant differences in the variance-ratio have been discovered after analysis of variance testing.

Tukey Test

The LSD test is not considered by some researchers [119] to be the most appropriate procedure for post-hoc comparisons because of the increased possibility of Type I errors. An alternative, more conservative test, is the Tukey test (sometimes called the Honestly Significant Difference test (HSD)). The Tukey test is based on the Studentised Range Statistic (q) and it involves comparing the difference between pairs of means, with a multiple of the standard error of a single mean. This multiple is given by the upper percentage point of the studentized range distribution, using the same level of significance as that used for the variance-ratio test ($p<.05$). The distribution has two parameters, namely m and *df*, where m is the number of means, *df* is the number of degrees of freedom of the residual mean square. For example for $m = 6$ and $df = 220$, the multiple (from 5% studentised range table) $= 4.03$. A significant difference is said to exist if the difference between 2 means exceeds:

$$Tukey\ multiple \times SE\ of\ a\ single\ mean$$

Unlike LSD test, there is an increased possibility of Type II errors (accepting the null hypothesis, when in fact it should be rejected and the alternative hypothesis accepted) when using the Tukey test.

Because of the increased possibility of Type I errors when using LSD test and Type II errors when using Tukey test, it was decided that, where appropriate, both tests would be used and the results assessed carefully. Any two means that are proven significantly different from each other in both tests can be considered significant with a good degree of certainty. However, where significance is found in only one test, the results will be considered with more caution.

(Note: When many pair-wise comparisons are being conducted, it is necessary to use both LSD and Tukey tests. However, when only 2 means are being assessed it is necessary to use only LSD test as the Tukey test will generate the same results.)

7.1.3 *t*-test

The related *t*-test is a parametric test which aims to compare the difference between two experimental conditions against the total variability of the scores. The assumptions underlying the *t*-test are identical to those underlying the analysis of variance test, so justification of the use of this test on the data has already been discussed. The statistic t represents the size of the differences between subjects' scores for the two conditions. In order to be significant the observed value of t has to be *equal to* or *larger than* the critical values of t found in the statistical tables for t. The formula for determining the t value is [120]:

$$t = \frac{\sum d}{\sqrt{\frac{N\sum d^2 - (\sum d)^2}{N-1}}} \tag{7.2}$$

where:

$\sum$ d = sum of differences between scores in the two conditions

$\sum$ d^2 = sum of squared differences

($\sum$ d)^2 = sum of differences squared

N = number of subjects

7.1.4 Testing for significant differences from zero

It is sometimes necessary, when looking for significant differences between means, to consider how significantly different from zero a series of means are. For example, suppose an analysis of variance test revealed an interaction between the order of presentation of appliances and session. In theory, the mean rating for orders of presentation in each session should be identical, as subjects are simply rating the same appliances in each session, only in an altered order of presentation. Thus the mean ratings for session A should be very similar to the mean ratings for session B for any order of presentation. Therefore the product of (A - B) should be very close to zero.

In some cases, it is necessary to conduct a statistical test to identify how significantly different from zero the difference in the means are. As with LSD test, it is necessary to calculate SE_{diff} for the correct number of means in question. For four orders of presentation and two sessions the number of means is 8. In this test, instead of the means being considered significantly different from each other, they are considered significantly different from zero (at $p<.05$) if the difference exceeds $2 \times (SE_{diff})$. This is a useful test for identifying the cause of an interaction between two variables.

7.1.5 The 'Underlining and Ordering' Method.

It is often confusing for a reader to be presented with line after line of numbers. Therefore, in a number of instances, the results were presented in a very simplistic manner. (This usually occurred when investigations were made of the significant differences between a group of means.) Instead of simply presenting the mean value of each variable, the mean values are arranged in order from smallest to largest, and those means are underlined where the variables are not significantly different from each other [111]. For example suppose:

A = 6

B = 7

C = 20

D = 19

If one carried out a test to determine the significant differences between the means, one may find the following relationship:

A B D C

This relationship suggests that there is no significant difference between means A and B, and between means B, D and C. However, A is significantly different from D and C. This underlining and ordering method often helps to simplify a seemingly complicated relationship. It is used in this thesis for just that purpose.

7.1.6 Correlations

The strength of the relationship between the values of two random variables can be identified by examining the correlation between the variables. In this study the two variables were sound level (in the form of various noise indices) and mean rating. Pearson Product Moment Correlation (a parametric test) was used to determine the correlations. Being a parametric test, the assumptions, as discussed in section 7.1.1 must be fulfilled. The correlation coefficient r is determined by the following formula:

$$r = \frac{\sum(x-\overline{x})(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2\sum(y-\overline{y})^2}} \tag{7.3}$$

where x and y are the two variables.

The significance of the correlation coefficient r can be determined by the use of tables that give critical values of r at various levels of probability. The observed value of r is significant at a given level of significance if it is *equal to* or *larger than* the critical value shown in the tables.

7.1.7 Linear Regression Analysis

Whereas correlation concerns the strength of the relationship between the values of two variables, regression analysis determines the nature of that relationship and enables one to make predictions from it. Again the two variables upon which regression analysis was used are sound level (in the form of various sound level indices) and mean rating, and one assumes that the relationships between them is linear. Regression analysis generates an equation that uses one of the variables to help explain the variation in the other variable. Also, from regression analysis it is possible to determine the amount of variation which is explained by the regression line (equivalent to the square of the ordinary correlation coefficient) The larger this value (referred to in the table as '% of variance accounted for') the better the data fits the regression line.

In this study, regression analysis was used to determine which of the variety of sound level indices investigated, best represented the subjective reaction to domestic appliance noise. In each case the mean subjective response (mean over all the subjects) was regressed against sound level, expressed in various sound level indices. As part of the regression analysis, the residuals (being the difference between the observation and the fitted value determined by the regression equation) were observed, as they are an indication of how well or poorly the model fitted the data. Plotting of residuals was particularly useful when investigating the homogeneity of variance assumption associated with the analysis of variance test (see section 7.1.1).

7.1.8 Polynomial Fitting

On occasions, it was obvious that the assumption of a linear relationship was not adequate in describing the data. In these cases a polynomial model was fitted to the data. Polynomials can generally be described as equations that involve powers of the x variable. For example:

$$y = B_0 + B_1 x_1 + B_2 x^n \tag{7.4}$$

where B_0 to B_2 are constants and n is the power to which the x variable is raised.

In cases were the relationship was non-linear, polynomial models were fitted, the data transformed and multiple regression analysis was performed.

7.1.9 Hotelling Test

When the data had been re-analysed assuming a non-linear relationship, a second correlation coefficient was generated, at it was important to investigate if this correlation coefficient was significantly different from that generated assuming a linear relationship. A t-test has been developed by H

Hotelling that allows such an investigation [121]. The formula of the test is:

$$t_{d_r} = (r_{12} - r_{13})\sqrt{\frac{(N-3)(1+r_{23})}{2(1 - r_{23}^2 - r_{12}^2 - r_{13}^2 + 2r_{23}r_{12}r_{13})}} \tag{7.5}$$

where:

N = number of appliances

r_{12} = correlation coefficient from analysis one

r_{13} = correlation coefficient from analysis two

r_{23} = intercorrelation (correlation between r_{12} and r_{13}

Using the normal t tables one can decide whether the value t_{d_r} represents a significant improvement in analysis two over analysis one.

7.1.10 Log Linear Analysis

Hypotheses 9, 11, 12, 13 and 14 require the examination of the relationship between different subjective ratings e.g. acceptability and usefulness. This kind of data can be described as 'categorical' in the sense that the data does not relate to a score but to a category - for example: acceptable, not acceptable, useful, not useful etc. Statistical packages have been developed to enable analysis of such data. The Statistical Package for the Social Sciences version X (SPSSX) includes a log linear model which was formulated specifically for the analysis of categorical data. The models are useful for uncovering the potentially complex relationships among the variables in a multiway cross tabulation. For each hypothesis (as mentioned above) it is assumed that there is a relationship e.g.'acceptability by annoyance' valid for all appliances. This relationship becomes the model for the analysis. The data can be presented in table form for each appliance. (see Table 7.1) The cells of the table contain the average rating for any particular appliance, for each of the categories. The statistical package then calculates expected cell counts based on the assumed model and evaluates how well the data fits the model (or by how much the observed and expected cell counts differ). If the

Table 7.1 A sample table showing categories of usefulness and acceptability.

Usefulness	Acceptable	Not Acceptable
1 Not very useful		
2 Quite useful		
3 Useful		
4 Very Useful		

table has many cells with small expected value (eg less than 5) it is advisable to pool the categories. This was necessary in the case of, for example 'not useful' and 'quite useful', and 'not annoying' and 'quite annoying'.

One way to assess how well a model fits the data is to examine the differences between the observed and expected cell counts based on the model. If the model fits the observed data well, and there is a valid relationship between, say, annoyance and acceptability for all appliances, a 'Z' value will be generated which should be greater than 1.96. By examining the Z values one can identify patterns of deviation from the model, in cases where the Z value is less than 1.96. This analysis was performed (where applicable) for each experimental group of appliances (where *group* does not refer to the type of appliance, but to the chosen grouping as described in Chapter 6 section 6.9.3 in relation to Hypothesis 5).

7.1.11 Bootstrapping

This technique allows one to generate the sampling distribution of the test statistic (which, in this study, is the difference between the squared correlation for two noise indices) and thus calculate the p value. This technique was used because the theoretical distribution for the difference between two squared correlations is complicated and is not tabulated. It is a relatively new statistical method. In this study it enabled an assessment of which noise index had performed statistically better or worse than any other.

7.2 Summary of use of statistical tests

A variety of statistical techniques have been described, which are used extensively to determine the success or failure of each research hypothesis. They were chosen because they were considered to be the techniques most suitable for examining the experimental data and for identifying relationships between the experimental variables under review. The techniques were used on the mean response for each appliance to overcome the problem that individuals react differently to noise stimuli. The techniques used have been:

1. Analysis of variance, which was used to partition the total variation in the data into components due to attributable causes. The F ratio test was then used to test whether a component due to a particular cause contributes significantly to the total variation.

2. Post-hoc comparisons (LSD and Tukey tests), which allowed the identification of treatment means that were significantly different from other treatment means, when the variance ratio was found to be significant.

3. t-test, which allowed comparison of the difference between two experimental conditions and the total variability of the scores.

4. Testing for significant differences from zero was sometimes used when identifying significant differences between means.

5. Underlining and ordering of results allowed the relationships between means to be clearly identified.

6. Pearson Product Moment Correlation, which allowed identification of the strength of the relationship between the values of two random variables.

7. Regression Analysis, (assuming linear and non-linear relationships) which allowed the evaluation of the nature of a relationship between two random variables and hence enabled one to make predictions of one from the other.

8. Hotelling test which indicated whether a linear or non-linear relationship best described the data.

9. Log linear analysis, which allowed the analysis of categorical data.

10. Bootstrapping, that indicated which noise level index performed better or worse than the rest.

The results of data analysis using this variety of statistical techniques, are presented in Chapter 8.

Chapter 8

Analysis and discussion of subjective rating experiments

In this Chapter, the research hypotheses are investigated by analysing the data generated by the objective and subjective experiments (as described in Chapters 5 and 6.) Each hypothesis will be discussed in the order in which it was presented in Chapter 4. For a detailed description of the statistical techniques used, refer to Chapter 7.

In general, a result is considered to be significant when a statistical test yields a value whose associated probability of occurrence is equal to or less than the significance level of $p = 0.05$ or $p = 0.01$.

Hypotheses to demonstrate the validity and reliability of the experimental data

8.1 Hypothesis 1

A subject's rating of the noisiness of domestic appliances will vary with the presentation of appliance noises with differing physical characteristics.

The mean noisiness ratings and standard deviations for each appliance are shown in Table 8.1. For further statistical summaries of these results, consult Appendix P. Table 8.2 presents

- A-weighted sound power level (L_{WA}),

- A-weighted sound pressure level (L_{pAav}),
- equivalent continuous A-weighted sound pressure level, 30 seconds ($L_{Aeq,30sec}$)
- maximum A-weighted sound pressure level (L_{Amax}),
- single event noise exposure level (L_{AX}),
- sound pressure level (L_{pav}),
- D-weighted sound pressure level (L_{pDav})
- Perceived Noise Level (PNL)

for each appliance.

Table 8.1 Mean noisiness ratings for four appliances.

Appliance	Mean Rating	Standard Deviation
1. Hoover 119 Vacuum Cleaner	5.48	1.069
2. Braun MC - 1 Food Processor	5.41	0.971
3. Moulinex 530 Liquidiser	4.75	1.039
4. Clairol 1200 Hair Dryer - Speed 1	3.69	0.871

Table 8.2 Measures of the noise of four appliances.

Appliance	L_{WA}	L_{pAav}	$L_{Aeq,30sec}$	L_{Amax}	L_{AX}	L_{pav}	L_{pDav}	PNL
Vacuum Cleaner	91.0	81.0	81.9	82.9	97.0	88.2	90.0	95.1
Food Processor	87.0	82.0	81.6	85.0	96.6	83.2	93.1	95.2
Liquidiser	82.0	76.0	75.4	76.4	90.5	77.1	83.8	89.7
Hair Dryer	80.0	70.0	69.4	70.7	84.4	73.4	79.8	86.1

It is evident that subjects' noisiness ratings did vary with the presentation of the four different appliance noises. The statistical significance of this can be determined using analysis of variance for all sources of variation (including any interaction effects) and using the mean noisiness rating. When significant variations were found the explicit nature of the variation was explored using Least Significant Difference Test (LSD), Tukey Test (Honestly Significant Difference) and *t*-test (see Chapter 7 section 7.1.2 and section 7.1.3 for a description of these tests). Table 8.3 presents the analysis of variance summary table.

Table 8.3 Summary table for Analysis of Variance.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	95.15	180	0.53		
Subjects	125.15	31	4.04	7.64	<.001
Session	1.41	1	1.41	2.67	
Presentation Order	0.70	3	0.23	0.44	
Appliances	128.93	3	42.98	81.3	<.001
Subject x Session	23.46	31	0.76	1.43	
Order x Session	1.06	3	0.35	0.65	
Appliance x Session	0.23	3	0.08	0.15	

The F values were significant at $p = .001$ level of significance for two sources of variation - subjects and appliances. The fact that the subject effect is highly significant reflects the way the subjects use the noisiness rating scale. Some subjects use high numbers, some use low numbers and some use all of the scale. It is expected that subjects will react differently, using a different frame of reference. Therefore for any sound, there will be a range of numbers due to subject differences. This, however, is not a limitation because, for any sound, the mean noisiness rating is used, which will counteract the effect of high and low values.

Discounting the variation caused by subjects, the variability of the noisiness ratings can be attributed largely to the different appliances. In other words, noisiness ratings varied with the presentation of different appliance noises. As the F value for appliances was significant at $p = .001$ level of significance, the research hypothesis may be said to be proved.

Having established that the means for the four appliances are significantly different, using LSD, Tukey and *t*-test, it is possible to examine which means are significantly different from which.

8.1.1 Least Significant Difference (LSD)

Applying the procedure outlined in Chapter 7, section 7.1.2, the standard error of the difference (SE_{diff}) between pairs of treatment means for this data was calculated, and there is a significant difference between any two means if it exceeds 2 x SE_{diff}, which for this data is 0.257. Using the ordering method described in Chapter 7, section 7.1.5 (whereby mean ratings are ordered from smallest to largest rating, and cases are underlined where there is no significant difference) the following relationship is observed:

$$\underline{1 \quad 2} \quad 3 \quad 4$$

This result demonstrates that there is a significant difference between mean noisiness ratings for all comparisons of means with the exception of appliance 1 (vacuum cleaner) and appliance 2 (food processor).

8.1.2 Tukey

Applying the procedure outlined in Chapter 7, section 7.1.2, for this data there is a significant difference between any two means if the difference exceeds (Tukey multiple x standard error of a single mean) or 0.33. Again, ordering the ratings from smallest to largest and underlining results where there is no significant difference gives:

$$\underline{1 \quad 2} \quad 3 \quad 4$$

This confirms the result of the LSD test.

8.1.3 *t*-test

The *t*-test outlined in Chapter 7, section 7.1.3 was applied to the data and the results obtained are presented in Table 8.4.

Table 8.4 *t*-test summary table.

Comparison of Appliances	t	Level of Significance
Vacuum Cleaner x Food Processor	0.87	not significant
Vacuum Cleaner x Liquidiser	4.05	<.001
Vacuum Cleaner x Hair Dryer	9.50	<.001
Food Processor x Liquidiser	4.01	<.001
Food Processor x Hair Dryer	12.90	<.001
Liquidiser x Hair Dryer	13.20	<.001

Significant differences can be observed between noisiness ratings for all combinations of appliances with the exception of the vacuum cleaner and food processor. Subjects' noisiness ratings for these appliances were very similar although the mean noisiness rating for the vacuum cleaner was greater than for the food processor.

8.2 Hypothesis 2

A subject's rating of the noisiness of domestic appliances will be consistent between two experimental sessions.

As explained in Chapter 6, section 6.9, an experimental sitting involved two sessions - session A and session B. The only difference between A and B was the order of presentation of appliances. To identify any significant differences in ratings between the two sessions, analysis of variance was carried out (a summary is presented in Table 8.3). The F value of 2.67 for the session variable was not significant at any of the significance levels of interest, for this experiment. It can be concluded that, for this particular experiment, ratings of noisiness were consistent between sessions.

However, during a number of subsequent experiments the session effect was identified as a significant source of variation. (See sections 8.1, 8.5.1, 8.5.2, 8.5.3 and 8.5.5). Table 8.5 presents the F values and associated significance levels for analysis of variance tests on other experimental data.

Table 8.5 F values and significance levels for the session variable.

Hypothesis	F value	Level of Significance
3	13.87	<.001
5 - 1	14.55	<.001
5 - 2	16.37	<.001
5 - 3	5.35	<.05
5 - 5	4.61	<.05

5 - 1,- 2,- 3 and - 5 in the table represent the particular group of appliances for which the session variable was significant. One possible explanation of this phenomenon is that subjects became less dependable and objective. During the experimental sessions associated with Hypothesis 1 subjects were requested to:

1. listen to and rate the noise level of four appliances,
2. complete a questionnaire (which usually required about 15 minutes of effort) and
3. listen to and rate the same four appliances, presented in a different order.

However, in the remaining experimental sessions, either there was no questionnaire to complete, or it was completed at the end of the session (for reasons described in Chapter 6, section 6.9.3). Thus the time between session A and session B was relatively short - usually less than two minutes.

Hypotheses relating objective quantities to subjective ratings

8.3 Hypothesis 3

A subject's rating of noisiness will depend on whether the subject is using the appliance or listening to it.

As explained in Chapter 6, section 6.9, subjects were required to rate the noise level of four domestic appliances under the following conditions:

1. while they were operating the appliances
2. while they were listening to the appliances being operated by another subject.

The mean noisiness ratings for the four appliances, for subjects as users and listeners, are presented in Table 8.6. (For further statistical summaries of the ratings see Appendix P.)

Table 8.6 Mean noisiness ratings for users and listeners.

Appliance	User (U)	Listener (L)	Mean	U minus L
1. Vacuum Cleaner	5.0313	5.5312	5.2812	-0.4999
2. Food Processor	6.4688	5.7500	6.1094	0.7188
3. Liquidiser	4.8433	4.5937	4.7187	0.2496
4. Hair Dryer	3.7500	3.6250	3.6875	0.1250

Analysis of variance was carried out for all parts of the experiment, including interaction effects, using the mean noisiness ratings. A summary of this information is given in Table 8.7.

The following effects were significant at $p < .001$ level of significance:

1. Subjects - an explanation for the significance of this source of variation has been given in section 8.1 of this chapter.
2. Session - an explanation for the significance of this source of variation has been given in section 8.2 of this chapter.

Table 8.7 Summary Table for Analysis of Variance.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	116.33	204	0.57		
Subjects	112.96	31	3.64	6.39	<.001
Session	7.91	1	7.91	13.87	<.001
Presentation Order	0.76	3	0.25	0.45	
Appliances	198.48	3	66.16	116.02	<.001
User/Listen state	1.41	1	1.41	2.47	
Order x Session	0.70	3	0.23	0.41	
Appliance x Session	0.36	3	0.12	0.21	
Order x User/Listen	1.32	3	0.44	0.77	
Appliance x User/Listen	12.11	3	4.04	7.08	<.001

3. Appliance - this is expected to be significant, according to Hypothesis 1 (noisiness ratings will vary with the presentation of different appliance noises).

4. Interaction between Appliance and User/Listener activity - this interaction was highly significant and suggested that there was no uniform pattern across all the appliances. For example, noisiness ratings did not always increase under user activity for all the appliances. This is evident from mean user/listener noisiness ratings in Table 8.6.

To investigate this interaction, it was necessary to carry out two analyses:

8.3.1 Identification of significant differences between the product of (user minus listener) noisiness ratings for each of the appliances.

The LSD test was used for this analysis. It is considered that there is a significant difference (at p=.05 level of significance) between the product of (user - listener) ratings if the difference exceeds 0.534. The ordering and underlining of non-significant differences gives the following relationship:

1 4 3 2

This implies that for appliance 1 (vacuum cleaner) there is a significant difference between (user minus listener) noisiness ratings when compared with (user minus listener) noisiness ratings for any other appliances. Subjects rated vacuum cleaner noise higher when listening. There was a slight tendency for the reverse phenomenon for the other three appliances. (This result is in fact confirmed by an analysis using Tukey test).

8.3.2 To consider how significantly different the product of (user minus listener) ratings is from zero.

If user or listener noisiness ratings are identical, then the difference between the ratings should equal zero. Using the method described in Chapter 7 section 7.1.4 it was deduced that the product of (user minus listener) noisiness ratings is significantly different from zero (at p=.05 level of significance) if the difference exceeds 0.46. From column 5 in Table 8.6 it can be seen that the product of (user minus listener) ratings is significantly different from zero for the vacuum cleaner and food processor. Subjects rated the noisiness of the vacuum cleaner higher while they were listening to the appliance being operated by another subject. For the food processor, however, the opposite is true - subjects rated its noisiness higher while they were using the appliance themselves. The ratings for the hair dryer and liquidiser were not significantly different from zero - ratings did not change significantly with the change of activity.

Since the product of (user minus listener) ratings was significant at p=.05 level of significance for the vacuum cleaner and food processor, the research hypothesis is said to be true for these appliances. Noisiness ratings will vary depending on whether the subject is using the appliance or listening to it. However, because the noisiness ratings of the liquidiser and hair dryer did not vary significantly, the research hypothesis is not true for these appliances.

8.3.3 Discussion

One possible explanation for the different user/listener ratings of the vacuum cleaner and food processor is that the sound levels of the user and listener positions were different. Therefore a further experiment was conducted to determine the changes that occurred with the change of subject position.

Vacuum cleaner measurement

Measurements of A-weighted sound pressure level, and tape recordings were made at the user and listener positions. The user operated the appliance in a specified location 1.5m in front of the listener. A microphone (Bruel and Kjaer type 4165) and preamplifier (Bruel and Kjaer type 2639) were connected to a noise level analyser (Bruel and Kjaer type 4427) to determine these values (using the 'event mode' function of the analyser as described in Chapter 5 section 5.2.1). Then the microphone was connected to a tape recorder (Nagra IV-SJ) for the A-weighted tape recording. Table 8.8 presents the analyser results:

Table 8.8 Measurements in User and Listener Locations of the Vacuum Cleaner.

Index	User Position	Listener Position
L_{pAav}	83.3	82.13

Subjects were effectively hearing the same A-weighted sound level - the difference between user and listener position being only 1.16 dBA, which is not a discernable difference to the human ear.

Figures 8.1 and 8.2 show the time averaged one-third octave frequency spectra for the user and listener positions. (Chapter 5, section 5.2 describes how the time-averaged spectra were obtained).

An interesting feature of the spectra is the increase in low frequency noise for the listener, for the frequencies:100, 125, 160, 200, and 250 Hz.

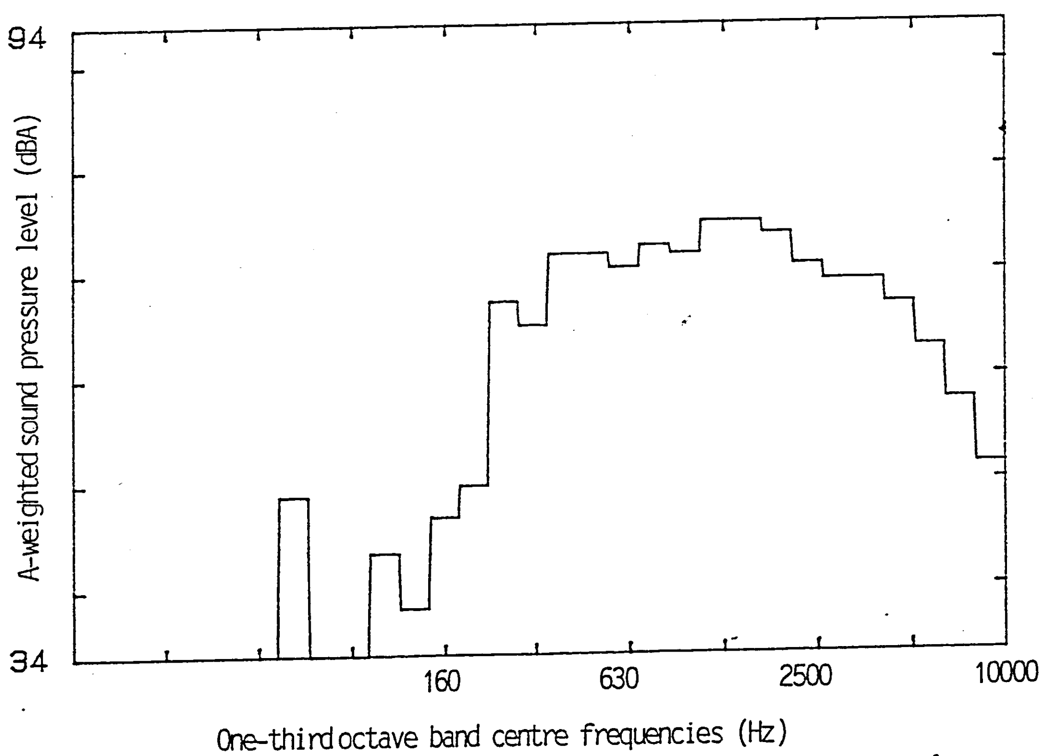


Figure 8.1 Time-averaged A-weighted sound pressure levels for each one-third octave centre frequency for the user position of the vacuum cleaner.

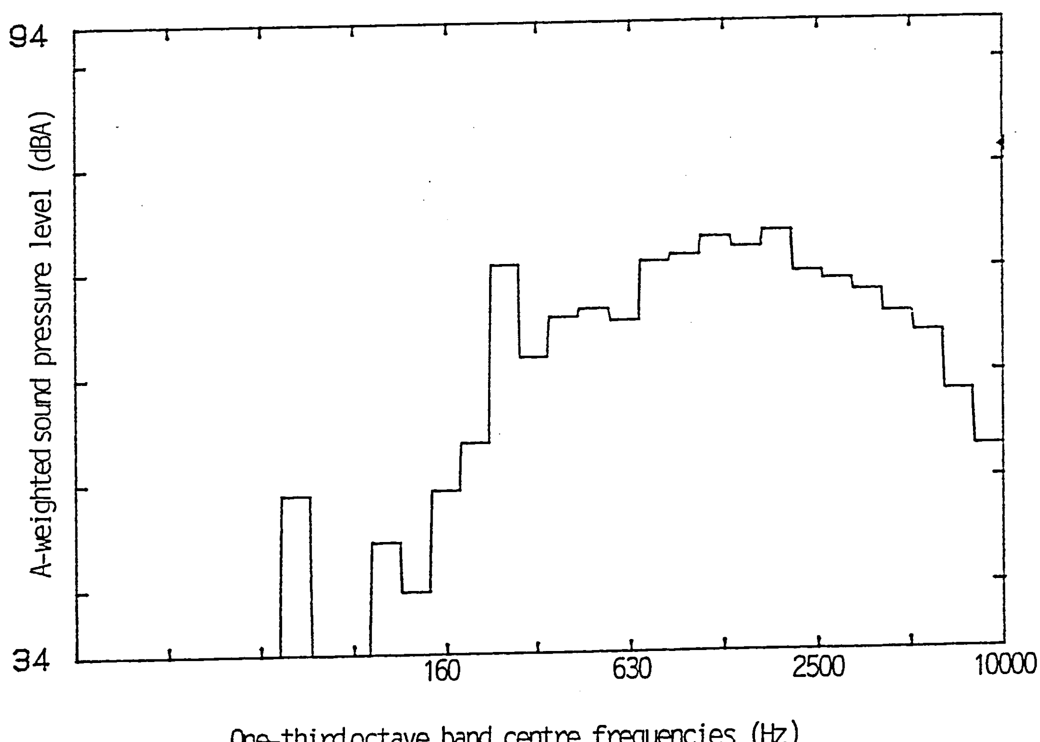


Figure 8.2 Time-averaged A-weighted sound pressure levels for each one-third octave centre frequency for the listener position of the vacuum cleaner.

In the listener position at 250 Hz there is a discrete frequency tone. This tone remains apparent during the averaging to obtain the time-averaged one-third octave frequency spectra. Thus one possible explanation for the increase in noisiness ratings while the subject is a listener, could be this increase in low frequency noise, especially at 160, 200 and 250 Hz.

Another possible explanation could be a directional noise emission component. However, for an upright vacuum cleaner, the most pronounced directivity is in the position where the user stands. No directional effects were obvious (for the frequencies investigated during the directionality measurements) at the side of the appliance.

The difference in user/listener spectra may be related to room modes (which is a frequency enhancement occurring at a particular frequency due to the location of the source and receiver, and the unique architecture of the room). However this is unlikely as the appliance was being moved during use which would not allow consistent excitation of room modes. It could also be argued that the listener would be concentrating more on the noise than the user and thus give higher noisiness ratings. However, one might then expect listener ratings to be higher for all the appliances investigated during this experiment. This did not happen for the remaining appliances.

In the absence of any other plausible explanation, it is suggested that the vacuum cleaner was rated as noisier by subjects as listeners because of the discrete frequency at 250 Hz although this was not confirmed by the questionnaire responses associated with this appliance.

Food processor measurement

Measurements of A-weighted sound pressure level, and a tape recording of the appliance noise levels were made at the user and listener positions of the food processor. The listener was located 1.0m from the user, in order that they were rating the same noise level. Table 8.9 presents the results of the measurements made using the 'event mode' program of the noise level analyser.

There was a difference in A-weighted sound pressure levels of 1.33 dBA

Table 8.9 Measurements in User and Listener Locations of the Food Processor.

Index	User Position	Listener Position
L_{pAav}	91.52	90.19

between user and listener positions. Therefore subjects were effectively hearing the same overall sound level. Thus this alone does not explain why noisiness ratings were lower under listener conditions. From the tape recordings a time averaged one-third octave frequency spectra was obtained for each position (see Figures 8.3 and 8.4).

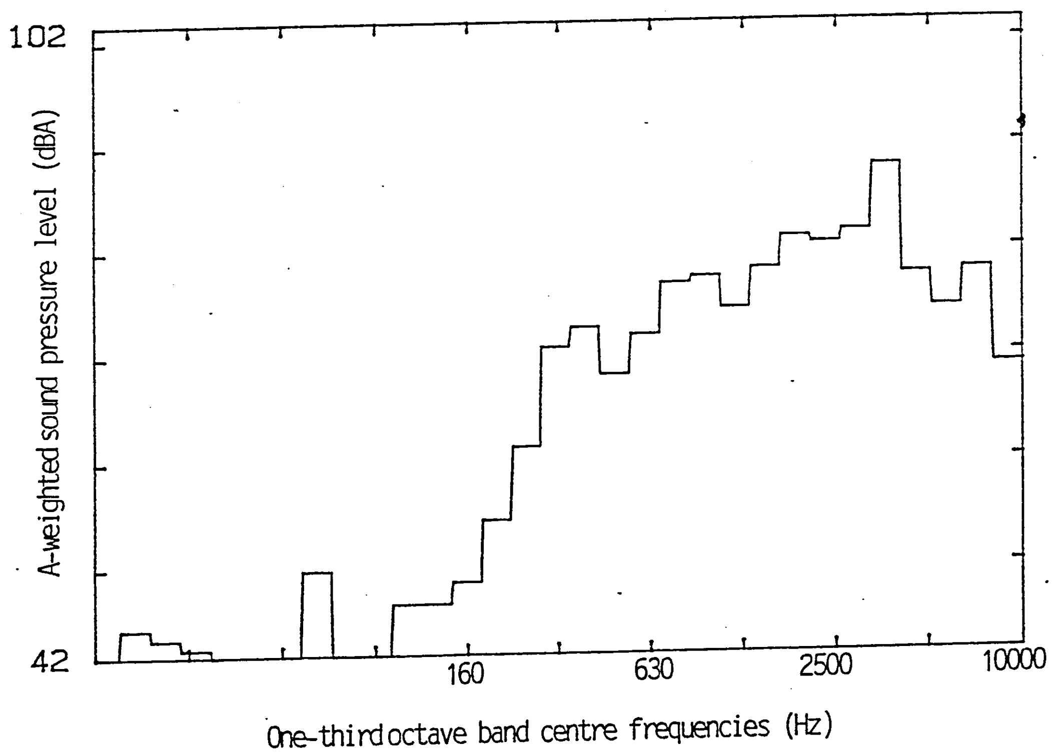


Figure 8.3 Time-averaged A-weighted sound pressure levels for each one-third octave centre frequency for the user position of the food processor.

It can be seen that for every one-third octave centre frequency the sound level is lower for the listener, than the user, with the exception of 4KHz

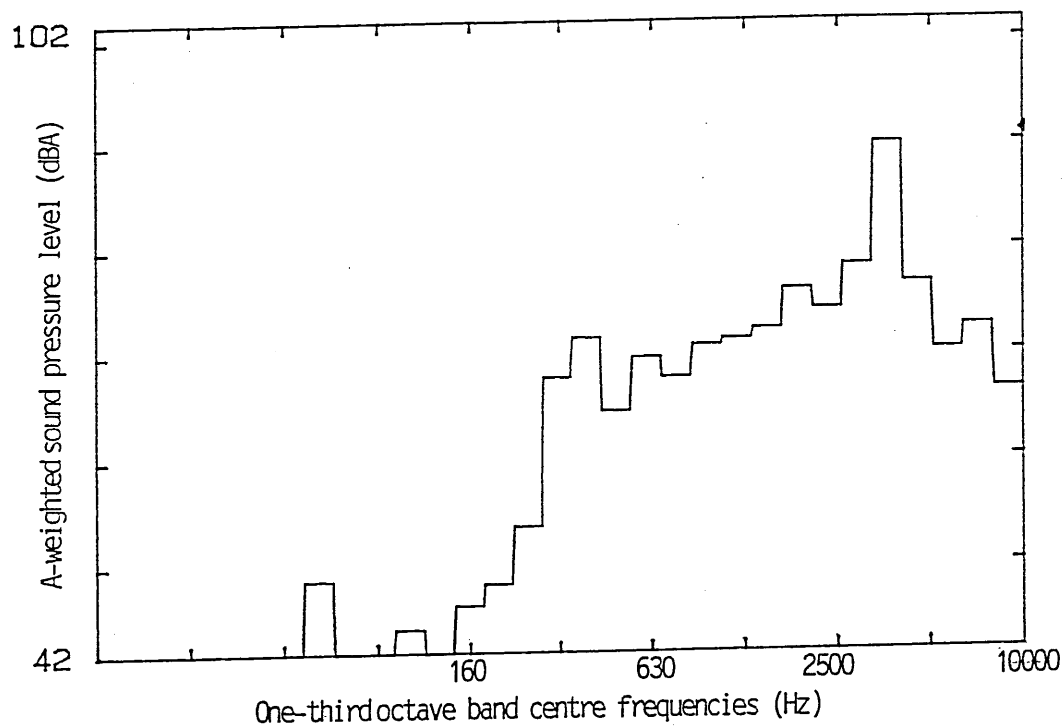


Figure 8.4 Time-averaged A-weighted sound pressure levels for each one-third octave centre frequency for the listener position of the food processor.

(where the level is 2 dB higher). Thus it is possible that, even though the overall sound level is only 1.33 dBA lower for the listener, the fact that some of the levels for the one-third octave centre frequencies are between 3 and 9 dBA lower for the listener could result in the noisiness ratings being lower for the listener than the user. Certainly the relatively lower level of the high frequency components could have a strong influence on the noisiness ratings, making them lower at the listener position. A-weighting of the sound pressure level does not adequately reflect this reduction at high frequencies.

8.4 Hypothesis 4

A subject's rating of the noisiness of an appliance will be conditioned by the duration of its operation.

As explained in Chapter 6 section 6.9.2 for this series of experiments, subjects were required to listen to the noise of four appliances. In session A the appliances were operated for 15 seconds and in session B they were operated for 30 seconds. Table 8.10 shows the mean noisiness ratings for the appliances in each session. (For further statistical summaries of the ratings see Appendix P).

Table 8.10 Mean noisiness ratings for appliances under increasing time conditions.

Appliance	Session A (15sec)	Session B (30 sec)	Mean	A minus B
1. Vacuum Cleaner	5.2187	5.5312	5.3750	-0.3125
2. Food Processor	5.6562	5.8750	5.7656	-0.2188
3. Liquidiser	4.8438	5.0000	4.9219	-0.1562
4. Hair Dryer	3.6875	3.8125	3.7500	-0.1250
ALL	4.8516	5.0457	4.9531	-0.1941

To test the validity of this hypothesis, analysis of variance was carried out, for all parts of the experiment, including interactions. The analysis of variance summary is given in Table 8.11.

Table 8.11 Summary table for Analysis of Variance.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	91.03	180	0.51		
Subject	105.94	31	3.42	6.76	<.001
Session	2.64	1	2.64	5.22	<.025
Presentation Order	1.37	3	0.46	0.91	
Appliances	146.34	3	48.78	96.46	<.001
Subject x Session	10.86	31	0.35	0.69	
Order x Session	4.92	3	1.64	3.24	<.025
Appliance x Session	0.33	3	0.11	0.22	

From Table 8.11 the following sources of variation were found to be significant:

1. Subjects - an explanation for the significance of this source of variation has been given in section 8.1 of this chapter.

2. Session - if the research hypothesis is not correct, this source of variation will not be significant as there would be no change in noisiness ratings between session A and session B. However this effect was significant at $p<.025$.

3. Appliance - according to Hypothesis 1 this source of variation is expected to be significant.

4. Interaction between order of presentation and session - this interaction must be investigated before considering the main sources of variation.

8.4.1 Interaction between Order of Presentation and Session

For each order of presentation of the appliances eg 1st, 2nd, etc., even though the order changes from session A to session B, the mean noisiness rating for each order should always be the same or similar. However, in this case there is a significant difference between mean ratings for each order in session A and session B, but this difference is not uniform across all orders of presentation. To investigate which order of presentation is significant, it is necessary to consider the differences between session A and session B ratings for each order of presentation of appliances. Table 8.12 shows the mean noisiness ratings for each order of presentation and the differences between session A and session B ratings.

Table 8.12 Mean noisiness ratings for orders of presentation of appliances.

Order of Presentation	Session A	Session B	A minus B
1st	4.5000	5.1563	-0.6563
2nd	4.9062	5.0625	-0.1563
3rd	4.9687	5.0625	-0.0938
4th	5.0313	4.9375	0.0938
ALL	4.8516	5.0547	-0.1941

In theory, the mean noisiness rating in session A minus the mean noisiness rating in session B should produce a result close to zero for each order of presentation of appliances. The analysis aimed to establish if any (session A minus session B) mean noisiness rating was significantly different from zero. Using the method described in Chapter 7 section 7.1.4 it was calculated that, (for the significance level p=.05), any result was significantly different from zero if it exceeded 0.435. It can be seen in Table 8.12 that this figure is exceeded for the 1st order of presentation. This suggests that, regardless of appliance type, the appliance presented first in the second session was always rated higher than when it was presented at any other time. One possible explanation for this is attributed to the fact that for the appliance presented first in the second session, this was the first time subjects had heard an appliance operated for 30 seconds in this experiment and so 30 seconds was a seemingly long time. Thus the appliance was rated as noisier than when presented at any other time in the second session.

8.4.2 Effect of Session

Accepting that there is an interaction occurring between session and order of presentation, which may influence the means slightly, the effect of session on noisiness ratings was investigated, to establish whether there is a significant difference between mean noisiness ratings in session A (15 second operation of appliance) and session B (30 second operation). Using LSD test, there is a significant difference (at p=.05 level of significance) between the mean noisiness rating for session A and session B if the difference exceeds 0.178. From Table 8.12 the mean rating for session A was 4.8516 and for session B was 5.0547. The magnitude of the difference between them = 0.1941, which exceeds the value of 0.178. It can be concluded that there is a significant difference between noisiness ratings in session A and session B at p=.05 level of significance. Although the interaction effect does influence the strength of conclusions drawn, there is a definite trend towards appliance noise levels being rated as noisier with the elongation of exposure.

Having identified a relationship between an increase in the magnitude of noisiness rating with an increase in the duration of appliance use, a second series of experiments aimed to investigate if the opposite relationship was true ie. ratings would decrease in magnitude with a decrease in duration of operation of appliances. For this series of experiments two appliances were used - a vacuum cleaner and a hair dryer, and they were presented for 30 seconds in session A and 15 seconds in session B. The mean noisiness ratings for session A and session B are given in Table 8.13.

Table 8.13 Mean noisiness ratings for appliances under decreasing time conditions.

Appliance	Session A (30 sec)	Session B (15 sec)	Mean	A minus B
1. Vacuum Cleaner	5.2500	5.1875	5.2187	0.0625
2. Hair Dryer	3.6250	3.6875	3.6563	-0.0625
ALL	4.4375	4.4375	4.4375	0.0000

Again analysis of variance was carried out for all parts of the experiment and the interactions. The summary is given in Table 8.14.

Table 8.14 Analysis of Variance summary table.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	7.58	28	0.27		
Subjects	36.25	15	2.42	8.93	<.001
Session	0.00	1	0.00	0.00	
Presentation Order	0.02	1	0.02	0.07	
Appliances	39.75	1	39.75	146.79	<.001
Subjects x Session	1.50	15	0.10	0.37	
Order x Session	1.28	1	1.28	4.72	<.05
Appliance x Session	0.03	1	0.03	0.11	

The most unexpected feature of this table is the F value of 0.00 for session effect. This indicates that the noisiness ratings in session A and session B were virtually identical. This is also evident in Table 8.13 where the mean value for both sessions A and B was 4.4375. This unusual effect contradicts the conclusions of the first experiment, where significant differences were apparent between session A and session B ratings.

8.4.3 Discussion

There are two possible explanations for this phenomenon:

1. 30 second duration of the appliance noise could conceivably produce an acclimatising effect on subjects. So any noise of lesser duration would be rated the same as a noise of 30 second duration.

2. A carry-over effect could be occurring, as a result of testing only 2 appliances, with a short space of time between sessions. A carry-over effect is observed when the subject's performance under one condition is seen as a reflection of their performance under a previously administered condition. The procedure for eliminating this effect is discussed in Chapter 10, section 10.2.

The noisiness ratings given for session A are probably absolute ratings for 30 second duration of the appliance noise, but the ratings for session B can not be considered as absolute ratings for 15 second duration of the noise.

It is difficult to arrive at any conclusion from the results of this experiment. The subjects had already been involved in a large number of experimental sittings when this experiment was repeated, and were possibly becoming too accustomed to the rating procedure. Time restrictions and the fear that subjects had become too accustomed to taking part in the subjective experiments prevented any further repetitions of this experiment.

The only conclusion one can draw from this fourth hypothesis is that subjective reactions did vary with the elongation of exposure to the appliance noise, where the appliance was first presented for 15 seconds and repeated for 30 seconds.

8.5 Hypothesis 5

A subject's rating of the noisiness of an appliance will vary in a way that is highly correlated to A-weighted sound power level L_{WA}.

If noisiness ratings are found to be highly correlated to A-weighted sound power level the following features would be apparent:

1. subjects would give identical noise ratings to appliances with identical A-weighted sound power levels (as measured according to the method described in Chapter 5 section 5.1.1).
2. noisiness ratings would reflect increasing magnitudes of A-weighted sound power level.

In attempting to identify these features, five experiments were carried out, each involving the use of six different appliances. These appliances were distributed among the five experiments in such a way that appliances of identical A-weighted sound power levels appeared in the same experiment. The results of each experimental group will be discussed separately. (For more detailed statistical summaries of the noisiness ratings for each group, refer to Appendix P).

8.5.1 Group 1 Appliances

Table 8.15 shows the mean noisiness rating and A-weighted sound power levels for each of the appliances in Group 1.

Table 8.15 Mean noisiness ratings and A-weighted sound power levels of Group 1 Appliances .

Appliance	Mean Rating	L_{WA}
1. Boots MD2 Hair Dryer - Speed 1	3.2292	69
2. Philips HR1907 Food Mixer - Speed 1	4.6458	69
3. Moulinex 722 Beauty Styler Hair Dryer - Speed 1	3.8125	71
4. Ronson Hotshot Hair Dryer - Speed 1	4.0208	73
5. Braun 1500 Compact Hair Dryer - Speed 2	3.9583	74
6. Kenwood Mini A345 Food Mixer - Speed 2	4.2500	74

Analysis of variance was carried out for all parts of the experiment including the interaction effects, largely to ensure that the appliance effect did not interact with any other source of variation. A summary of analysis of variance is given in Table 8.16.

Table 8.16 Analysis of Variance Summary Table for Group 1 Appliances.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	68.03	220	0.31		
Subjects	206.78	23	8.99	29.07	<.001
Session	4.5	1	4.5	14.55	<.001
Presentation Order	4.57	5	0.91	2.96	<.025
Appliances	53.28	5	10.66	34.46	<.001
Subjects x Session	6.67	23	0.29	0.94	
Order x Session	11.13	5	2.23	7.2	<.001
Appliance x Session	1	5	0.2	0.65	

The following sources of variation were found to be highly significant:

1. Subjects - see section 8.1 for explanation.

2. Session - see section 8.2 for explanation.

3. Presentation order.

4. Appliances.

5. Interaction between order of presentation and session.

Interaction between order of presentation and session

This interaction must be investigated rather than the main effects of session and order. As described in section 8.4.1 for each order of presentation of appliances, e.g. 1st, 2nd etc, even though the order changes from session A to session B, the mean noisiness ratings for each order should always be the same or similar. However, in this case there was a significant difference between mean noisiness ratings for each order in session A and session B, but the difference was not uniform across all orders of presentation. To determine which order is significant it is necessary to consider the differences between session A and session B ratings for each order of presentation of appliances. Table 8.17 presents the mean noisiness ratings for each order of presentation of appliances, and the difference between session A and session B ratings.

Table 8.17 Mean noisiness ratings for each order of presentation of appliances.

Order	Session A	Session B	A - B
1st	3.3750	4.1250	-0.7500
2nd	3.5833	4.2083	-0.6250
3rd	3.9583	4.1250	-0.1667
4th	3.8333	4.2500	-0.4167
5th	4.1667	4.0833	0.0834
6th	4.2500	3.8750	0.3750
ALL	3.8611	4.1111	-0.2500

In theory, the mean noisiness rating in session A minus the mean noisiness rating in session B should produce a result close to zero. This analysis aimed to establish how significantly different from zero was the difference in means. Using the method described in section 7.1.4, Chapter 7, a result is considered to be significantly different from zero if it exceeds 0.331. From Table 8.17 it can be seen that this was exceeded for Order of Presentation 1, 2, 4 and 6.

Because there is no interaction between appliance and session, it is acceptable to consider the mean noisiness ratings over the two sessions. Using LSD test there is considered to be a significant difference between any two means, at p=.05 level of significance, if the difference exceeds 0.227. Again using the ordering and underlining method (where means are ordered from smallest to largest and underlined where there is no significant difference between two means) the following result is obtained:

$$1 \quad \underline{3 \quad 5 \quad 4} \quad 6 \quad 2$$

Thus it can be concluded that subjects were not able to distinguish appliances 3, 4 and 5 from each other. Ordering the appliances in order of magnitude of A-weighted sound power level gives the following pattern:

$$(1 \quad 2) \quad 3 \quad 4 \quad (5 \quad 6)$$

where appliances 1 and 2, and 5 and 6 have identical A-weighted sound power levels. For this group of appliances, neither of the previously mentioned features are apparent. Appliance 1 received the smallest noisiness rating, while appliance 2 (which should have received an identical rating) received the largest rating. Appliances 5 and 6 did not receive the same rating either. Subjects were unable to distinguish between the noisiness of appliances 3, 4 and 5 even though their sound power levels were different.

8.5.2 Group 2 Appliances

Table 8.18 shows the mean noisiness rating for each appliance in this group and the A-weighted sound power levels for each appliance.

Table 8.18 Mean noisiness ratings and A-weighted sound power levels of Group 2 Appliances.

Appliance	Mean Rating	L_{WA}
1. Electrolux 520S Vacuum Cleaner	4.1250	77
2. Braun 1200 Supercompact Hair Dryer - Speed 1	3.5625	76
3. Philips HM3060 Food Mixer - Speed 1	4.5417	75
4. Philips TX2000 Liquidiser - Speed 1	5.3750	76
5. Moulinex 722 Beauty Styler Hair Dryer - Speed 2	4.8333	78
6. Boot MD2 Hair Dryer - Speed 2	3.9729	77

Analysis of variance was carried out on the data from this group of appliances and a summary of the results is given in Table 8.19.

Table 8.19 Analysis of Variance Summary Table for Group 2 Appliances.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Value	Significance Level
Residual	116.64	220	0.53		
Subjects	167.28	23	7.27	13.72	<.001
Session	8.68	1	8.68	16.37	<.001
Presentation Order	1.57	5	0.31	0.59	
Appliances	101.40	5	20.28	38.25	<.001
Subjects x Session	7.65	23	0.33	0.63	
Order x Session	5.19	5	1.04	1.96	
Appliance x Session	0.86	5	0.17	0.32	

The following sources of variation were highly significant:

1. Subjects - see section 8.1 for explanation.

2. Session - see section 8.2 for explanation.

3. Appliances.

Because the appliance effect did not interact with session, mean noisiness ratings over the two sessions can be considered. LSD was used to investigate significant differences between mean ratings of noisiness. There is considered to be a significant difference between any two means if the difference exceeds 0.297. Ordering appliance ratings from smallest to largest gives:

$$2 \quad \underline{6 \quad 1} \quad \underline{3 \quad 5} \quad 4$$

Ordering appliances according to the magnitude of A-weighted sound power level gives:

3 (2 4) (1 6) 5

Subjects' noisiness ratings do not reflect the order of magnitude of A-weighted sound power level. Noisiness ratings should have been identical for appliances 2 and 4 - clearly subjects did not rate these the same. According to A-weighted sound power level, appliances 3 and 5 should have received the smallest and largest ratings respectively. Subjects were unable to distinguish between them. The noisiness ratings given for appliances 1 and 6, however, were not significantly different from each other. But they do not reflect the order of magnitude of A-weighted sound power level.

8.5.3 Group 3 Appliances

In Table 8.20 are given the mean noisiness ratings and A-weighted sound power levels of the appliances included in Group 3.

Analysis of variance was carried out and a summary is contained in Table 8.21.

The following sources of variation were significant:

Table 8.20 Mean noisiness ratings and A-weighted sound power levels for Group 3 Appliances.

Appliance	Mean Rating	L_{WA}
1. Electrolux ZA65 Vacuum Cleaner	3.6667	79
2. Prestige L2001 Food Processor	4.2708	80
3. Electrolux 350E Vacuum Cleaner	3.8125	79
4. Kerstar C606 Supreme Vacuum Cleaner	4.1250	80
5. Clairol 1200 Hair Dryer - Speed 1	3.8958	80
6. Electrolux 345 Vacuum Cleaner	4.3750	80

Table 8.21 Analysis of Variance Summary Table for Group 3 Appliances.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Values	Significance Level
Residual	104.07	220	0.47		
Subjects	184.41	23	8.02	16.95	<.001
Session	2.53	1	2.53	5.35	<.025
Presentation Order	7.60	5	1.52	3.21	<.01
Appliances	18.39	5	3.68	7.78	<.001
Subjects x Session	10.05	23	0.44	0.92	
Order x Session	4.49	5	0.90	1.90	
Appliance x Session	1.28	5	0.26	0.54	

1. Subjects - see section 8.1 for explanation.
2. Session - see section 8.2 for explanation.
3. Order of Presentation.
4. Appliances.

Order of presentation of the appliances

Table 8.22 presents the mean noisiness ratings for each order of appliance presentation. In theory, the mean ratings for the six orders of presentation

Table 8.22 Mean noisiness ratings for Order of Presentation of Appliances.

Order of Presentation	Mean
1st	3.7292
2nd	3.9167
3rd	4.1875
4th	4.1875
5th	4.1042
6th	4.0218

should be approximately the same, as the figures are calculated from the rating for each of the six appliances. Using LSD it is possible to establish which of the means are significantly different from which other means and there is considered to be a significant difference between any two means if the difference exceeds 0.281, which results in the following relationship:

1 2 6 5 (3 4)

This overlapping confuses any conclusions, but an over-riding conclusion that can be drawn from these results is that the mean for the 1st order of presentation is significantly different from all other means, with the exception of order of presentation 2. If one carries out a visual analysis of

Table 8.22 it is apparent that, the noisiness ratings are always lower for order of presentation 1 than for any of the other presentations. The ratings for any other order of presentation are very similar. This might suggest that, regardless of appliance type, the appliance presented first in this experiment is always rated lower than when presented at any other time.

Difference between mean noisiness ratings

Investigation of any significant differences between mean noisiness ratings for each appliance can be carried out using LSD test, where there is considered to be a significant difference between any two means if the difference exceeds 0.281. Ordering mean noisiness ratings from smallest to largest gives:

1 3 5 4 2 6

Ordering appliances according to the magnitude of A-weighted sound power level, from smallest to largest gives:

(1 3) (2 4 5 6)

For this group of appliances, where the A-weighted sound power levels of the 6 appliances were very similar, subjects, were unable to distinguish between appliances 1, 3 and 5, 5 and 4, and 4, 2 and 6. Appliance 5 should have received the same noisiness rating as appliances 2, 4 and 6, but subjects were unable to distinguish it from appliances 1 and 3. Also, appliance 2 should have been rated lower than appliances 4 and 5. In fact, it was rated higher than these appliances.

8.5.4 Group 4 Appliances

Table 8.23 contains the mean noisiness ratings and A-weighted sound power levels of the appliances included in Group 4.

Table 8.23 Mean noisiness ratings and A-weighted sound power levels of Group 4 Appliances.

Appliance	Mean Rating	L_{WA}
1. Kenwood Chef A901 Food Mixer - Speed 4	5.2083	83
2. Electrolux 350E Vacuum Cleaner - Superboost	4.5208	82
3. Moulinex 530 Liquidiser	5.0625	82
4. Braun 1200 Supercompact Hair Dryer - Speed 2	4.4375	81
5. Ronson Hotshot Hair Dryer - Speed 2	4.5833	82
6. Braun 1500 Compact Hair Dryer - Speed 3	3.9792	81

Analysis of variance was carried out on all parts of the experiment and interactions. (See Table 8.24).

Table 8.24 Analysis of Variance Summary Table for Group 4 Appliances.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Values	Significance Levels
Residual	82.39	220	0.37		
Subjects	172.99	23	7.52	20.08	<.001
Session	0.22	1	0.22	0.59	
Presentation Order	1.74	5	0.35	0.93	
Appliances	47.82	5	9.56	25.54	<.001
Subjects x Session	5.44	23	0.24	0.63	
Order x Session	6.19	5	1.24	3.31	<.01
Appliance x Session	0.19	5	0.04	0.1	

The highly significant sources of variation were:

1. Subjects - see section 8.1 for explanation
2. Appliances
3. Order by session interaction

Interaction between order of presentation and session

To investigate which order of presentation was significantly different from the rest over the two sessions, it was necessary to investigate how significantly different from zero the product of session A minus session B was for each order. Using the method described in section 7.1.4, Chapter 7, a result was considered to be significantly different from zero if it exceeded 0.353. Table 8.25 presents the mean noisiness ratings for each order of presentation, and the product of session A minus session B.

Table 8.25 Mean noisiness ratings for Order of Presentation of Appliances.

Order of Presentation	Session A	Session B	A minus B
1st	4.2083	4.7500	-0.5417
2nd	4.4583	4.7500	-0.2917
3rd	4.6667	4.7500	-0.0833
4th	4.6667	4.6250	0.0417
5th	4.8333	4.5833	0.2500
6th	4.7917	4.5000	0.2917
ALL	4.6042	4.6597	-0.055

Thus it can be seen that for order of presentation 1 the product of session A minus session B is significantly different from zero, and suggests that the appliance presented 1st in the second session was always rated higher than when presented at any other time as found in earlier tests (section 8.4.1).

Using LSD test to investigate significant differences between mean noisiness ratings, there is considered to be a significant difference between any 2 means if the difference exceeds 0.25. This leads to the following ordering relationship:

$$6 \quad \underline{4 \quad 2 \quad 5} \quad \underline{3 \quad 1}$$

Ordering by magnitude of A-weighted sound power level gives:

$$(4 \quad 6) \quad (2 \quad 3 \quad 5) \quad 1$$

If noisiness ratings are found to correlate highly with A-weighted sound power level, then appliances 4 and 6 should have received the same noisiness ratings, as should appliances 2, 3 and 5. Subjects were unable to distinguish between appliances 1 and 3, and also 4, 2 and 5.

8.5.5 Group 5 Appliances

Mean noisiness ratings and A-weighted sound power levels of the appliances contained in group 5 are given in Table 8.26.

Table 8.26 Mean noisiness ratings and A-weighted sound power levels of Group 5 Appliances.

Appliance	Mean Rating	L_{WA}
1. Kenwood Chef A901 and Liquidiser - Speed 4	5.1875	85
2. Hoover 119 Vacuum Cleaner	5.3125	91
3. Moulinex 241.1 Liquidiser	5.2708	84
4. Braun MC-1 Food Processor	5.9583	87
5. Hoover U2002 Vacuum Cleaner	6.1875	88
6. Robot Chef RC3 Food Processor	5.0625	85

Analysis of variance on all parts of the experiment was carried out and the results are displayed in Table 8.27.

The highly significant sources of variation were:

1. Subjects - see section 8.1 for explanation.

2. Session - see section 8.2 for explanation.

Table 8.27 Analysis of Variance Summary Table for Group 5 Appliances.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Values	Significance Levels
Residual	73.07	220	0.33		
Subjects	71.91	23	3.13	9.41	<.001
Session	1.53	1	1.53	4.61	<.05
Presentation Order	1.27	5	0.25	0.76	
Appliances	50.85	5	10.17	30.62	<.001
Subjects x Session	3.39	23	0.15	0.44	
Order x Session	0.74	5	0.15	0.45	
Appliance x Session	1.24	5	0.25	0.75	

3. Appliances.

Using LSD to determine significant differences between mean noisiness ratings, there is considered to be a significant difference between any two means if the difference exceeds 0.235. This gives the following relationship:

6 1 3 2 4 5

Ordering appliances according to A-weighted sound power level gives:

3 (1 6) 4 5 2

There was no significant difference between noisiness ratings for appliances 1 and 6, which had identical A-weighted sound power levels. However, appliance 3 should have received the smallest noisiness ratings and appliance 2 the largest, according to magnitude of the A-weighted sound power level. Subjects were not able to distinguish between these two appliances, and gave appliance 6 the smallest noisiness ratings and appliance 5 the largest.

Summary of analysis of Hypothesis 5

Within each group, the results demonstrate that:

- mean noisiness ratings vary significantly even when A-weighted sound power levels were identical.
- the rank order of noisiness ratings is not the same as that of A-weighted sound power levels.

Thus it is concluded that ratings of noisiness did not appear to vary in a way that was comparable with the magnitude of A-weighted sound power levels.

8.5.6 Discussion of Hypothesis 5

The mean noisiness ratings for groups 1 to 5 were as follows:

1 = 4.0

2 = 4.4

3 = 4.0

4 = 4.6

5 = 5.5

Even though the magnitude of sound power levels increased from group 1 to 5, it is apparent that it is only at the highest sound power levels that subjects are really discriminating between appliance noise levels. In hindsight, each group should contain some appliances of the same sound power level and some appliances with widely differing sound power levels to overcome this lack of scale sensitivity (see Chapter 10, Section 10.2). The design chosen does not satisfactorily demonstrate the hypothesis, and there is, therefore, a lack of sensitivity in the subsequent hypotheses.

8.6 Hypothesis 6

A subject's rating of the noisiness of an appliance will be related to some noise index (other than L_{WA}), such as L_{pAav}, L_{pDav}, PNL, L_{Amax}, $L_{Aeq,T}$

and L_{AX}.

The aim of this hypothesis was to identify the correlation between noisiness ratings and a number of noise indices. Although the analysis previously described demonstrated that noisiness ratings were not comparable with A-weighted sound power levels in magnitude, the strength of the relationship was not established (i.e. the correlation between noisiness ratings and A-weighted sound power levels). To test this hypothesis, the mean noisiness ratings of the thirty appliances investigated during testing of Hypothesis 5, were correlated with a number of noise indices to determine which gave the best correlation. For the analysis of the remaining hypotheses the data for the 5 groups of appliances was pooled to simplify the analysis and generate an overall scenario. Although not ideal from the point of view of the constraints mentioned in section 8.5.6 this was the only way in which such data could be obtained.

The correlations between mean noisiness ratings and noise indices were calculated and correlation coefficients are given in Table 8.28.

Table 8.28 Correlation coefficients for mean noisiness ratings and various noise indices.

Index	Correlation Coefficient	Significance Level
L_{WA}	0.687	.001
L_{pAav}	0.815	.001
$L_{Aeq,30sec}$	0.882	.001
L_{Amax}	0.874	.001
L_{AX}	0.877	.001
PNL	0.821	.001
L_{pav}	0.762	.001
L_{pDav}	0.808	.001

Regression analysis was also carried out. Mean noisiness ratings were regressed against each of the noise indices. The results are given in Table 8.29 where ** represents a significance level of .001. Plots of each index against mean noisiness rating are presented in Appendix Q.

Investigation of the plots of mean noisiness rating vs the various noise

Table 8.29 Regression analysis for mean noisiness ratings against noise indices.

Index	Intercept Coeffic.	Slope Coeffic.	F value	% Variance
L_{WA}	-2.785	0.09267	25.05 **	47.20
L_{pAav}	-3.644	0.110	55.30 **	66.40
$L_{Aeq,30sec}$	-3.950	0.117	98.51 **	77.80
L_{Amax}	-4.120	0.117	90.61 **	76.40
L_{AX}	-5.770	0.118	93.43**	77.00
PNL	-5.290	0.0.112	57.82 **	67.40
L_{pav}	-2.407	0.091	38.88 **	58.10
L_{pDav}	-4.159	0.107	52.60 **	65.30

indices, presented in Appendix Q, suggests that the relationship between noise rating and the noise indices is not in fact linear - see Figure 8.5.

Therefore the data was re-analysed by fitting a polynomial to the data. A general polynomial is of the form:

$$y = Ax^n + Bx^{n-1} + Cx^{n-2}....Z \tag{8.1}$$

where A, B, C to Z are constants.

To simplify the fitting procedure, if one assumes that the values of y are dominated by the term containing the highest power, namely:

$$y = Ax^n \tag{8.2}$$

than it is possible to estimate n by transforming the data. Values of log_{10} (y) (noise rating) and of log_{10} (x) (noise index under investigation) may be obtained and a regression analysis performed on these data. If the assumption is valid, then the resulting equation will be of the form:

$$log_{10}\, y = log_{10}\, A + n log_{10}\, x \tag{8.3}$$

The value of n may be obtained from the slope of the regression line. Such analysis was carried out for the individual noise indices and the following n values obtained (see Table 8.30):

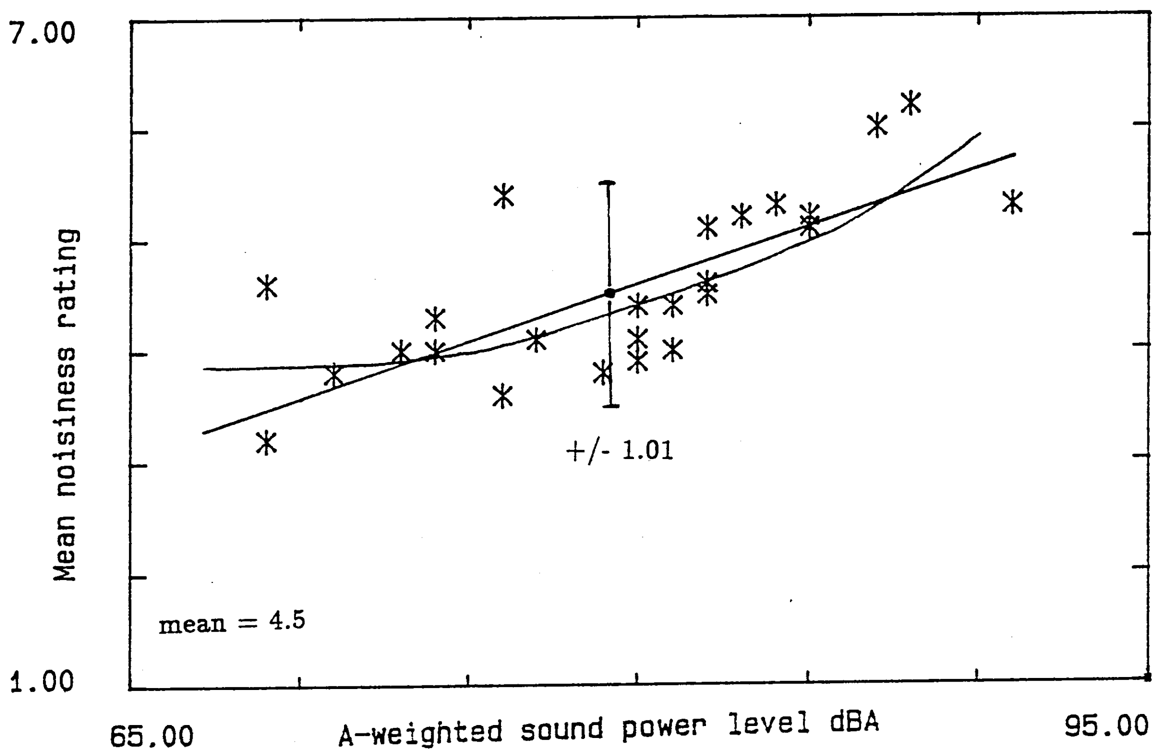


Figure 8.5 Mean noisiness ratings vs A-weighted sound power level for each appliance.

Table 8.30 Values of n for the various noise indices under investigation.

Noise index	Value of n	%Variance accounted for
L_{WA}	1.56	53.0
L_{pAav}	1.77	68.0
$L_{Aeq,30sec}$	1.84	79.4
L_{Amax}	1.87	78.4
L_{AX}	2.23	78.9
PNL	2.11	71.4
L_{pav}	1.50	58.5
L_{pDav}	1.88	67.0

Where the percentage of variance accounted for is of the order of 50%, it may be that the simplifying assumption is not a good one. Nevertheless, the procedure has been used for assessing the highest power of the independent variable required. As most of the n values lie close to 2, it was decided that the value of n adopted for further analysis would be 2. The exception to this is for unweighted sound pressure level where the value of 1.5 was used. Multiple regression analysis was repeated using the polynomial model of the form:

$$y = Ax^2 + Bx + C \tag{8.4}$$

where:

A, B and C are constants

y represents noisiness rating

x represents the noise index under investigation

The results are presented in Table 8.31.

Table 8.31 Regression analysis for mean noisiness ratings against noise indices assuming a polynomial model.

Index (x)	Correlation Coeff.	Signif. Level	Intercept Coeff.	x	x²	F Value	%variance accounted for
L_{WA}	0.727	.001	26.4	-0.65	0.005	15.18	52.9
L_{pAav}	0.824	.001	13.6	-0.35	0.003	28.62	67.9
$L_{Aeq,30sec}$	0.891	.001	10.6	-0.28	0.003	52.18	79.4
L_{Amax}	0.885	.001	11.5	-0.30	0.003	48.94	78.4
L_{AX}	0.888	.001	16.3	-0.39	0.003	50.54	78.9
PNL	0.845	.001	34.7	-0.80	0.005	44.67	71.4
L_{pav}	0.765	.001	03.6	-0.06	0.001	19.03	58.5
L_{pDav}	0.819	.001	17.8	-0.43	0.003	27.01	67.0

For each noise index, the correlation coefficient for the polynomial relationship is greater than for the linear relationship. Using the Hotelling technique described in Chapter 7, Section 7.1.9, it was determined that the correlation coefficient obtained for the polynomial fitting is significantly better statistically than that obtained assuming a linear relationship (at .0005 level of significance for all noise indices, except unweighted sound pressure level, where the significance level was 0.1). Figure 8.5 shows that the polynomial describes the actual data more successfully than the linear relationship.

The size of the correlation coefficient for A-weighted sound pressure level, when compared with the correlation coefficient of the maximum A-weighted sound pressure level, probably reflects the way the A-weighted sound pressure levels were measured (i.e. time-averaged one-third octave sound pressure level values).

Although the correlation coefficients for all the noise indices investigated were significant at $p<.001$ level of significance, in terms of the percentage of variance accounted for by the regression analysis, A-weighted sound power level and sound pressure level proved the least successful indices. Equivalent continuous A-weighted sound pressure level and single event noise exposure level were the most successful indices in terms of the percentage of variance accounted for.

The significance of the correlation coefficient for A-weighted sound power level index seems to contradict the results of the previous analysis. However, the previous analysis only compared mean noisiness ratings for the different appliances to determine which were significantly different from each other. The present analysis is concerned with investigating the relationship between mean noisiness ratings and A-weighted sound power levels.

Before identifying the index (or indices) that were the most successful in correlating with subjective reactions to domestic appliance noise, an attempt was made to improve the correlations obtained for the perceived noise level index, by accounting for the presence of pure tones (discrete frequencies) in the appliance noise spectra, and correcting for these tones. Tone corrections were added in cases where the frequency spectra of the domestic appliances demonstrated tonal components or other pronounced irregularities. The size of the tone correction added was determined using the method described in

BS 5727 - British Standard Method for describing aircraft noise heard on the ground [63]. Table 8.32 presents the size of correction added for each appliance.

Having added the tone corrections to Perceived Noise Level values, correlation and regression analysis were repeated, with the following results (see Table 8.33)

When comparing these results with those of Tables 8.28 and 8.29 it can be seen that the procedure designed to correct for the presence of tonal components did not improve the effectiveness of the Perceived Noise Level index - the correlation coefficient, although still highly significant, is lower than previously, as is the amount of variance explained by the fitted regression equation.

To determine statistically which index (or indices) performed the best, it was necessary to perform a statistical test known as 'Bootstrapping' (see Chapter 7 section 7.1.11 for an explanation of this test). Basically, this test allows the investigation of whether the correlation coefficients of two indices are significantly different by investigating how significantly different from zero is the result of

$$r_1^2 - r_2^2 \tag{8.5}$$

which represents the squared correlation of index 1 less the squared correlation of index 2. If the indices are both equally good then the results should be close to zero. Using the bootstrapping method the following relationship was obtained:

$$L_{WA} \quad L_{pav} \quad L_{pDav} \quad L_{pAav} \quad \text{PNL} \quad L_{Amax} \quad L_{AX} \quad L_{Aeq,30sec}$$

The A-weighted sound power level index was significantly worse than the other indices. It is not possible to distinguish between Perceived Noise Level and sound pressure level (linear, D-weighted and A-weighted). Maximum A-weighted sound pressure level, single event noise exposure level and

Table 8.32 Appliances with discrete frequencies.

Appliance	Correction Added
Clairol 1200 Hair Dryer - Speed 1	4.04
Boots MD2 Hair Dryer - Speed 1	2.48
Boots MD2 Hair Dryer - Speed 2	2.52
Moulinex 722 Hair Dryer - Speed 1	1.71
Moulinex 722 Hair Dryer - Speed 2	2.24
Braun 1500 Compact Hair Dryer - Speed 2	2.55
Braun 1500 Compact Hair Dryer - Speed 3	1.80
Ronson Hotshot Hair Dryer - Speed 1	2.97
Ronson Hotshot Hair Dryer - Speed 2	2.24
Braun Supercompact 1200 Hair Dryer - Speed 1	1.81
Braun Supercompact 1200 Hair Dryer - Speed 2	1.56
Electrolux 520S Vacuum Cleaner	2.42
Electrolux ZA65 Vacuum Cleaner	2.29
Electrolux 350E Vacuum Cleaner	1.57
Electrolux 350E Vacuum Cleaner - Superboost	1.18
Electrolux 345 Vacuum Cleaner	2.69
Kerstar C606 Supreme Vacuum Cleaner	0.48
Hoover 119 Vacuum Cleaner	3.30
Hoover U2002 Vacuum Cleaner	0.90
Philips HR1907 Food Mixer - Speed 1	1.21
Philips HM3060 Food Mixer - Speed 1	1.16
Kenwood Mini A345 Food Mixer - Speed 2	1.55
Kenwood Chef Food Mixer	2.40
Philips TX2000 Liquidiser - Speed 1	1.12
Moulinex 530Liquidiser	2.88
Moulinex 241.2 Liquidiser	4.82
Kenwood Chef with Liquidiser	2.52
Braun MC-1 Food Processor	4.50
Robot Chef RC3 Food Processor	2.25
Prestige L2001 Food Processor	2.95

Table 8.33 Correlation between Tone Corrected Perceived Noise Level and mean noisiness ratings.

Index	r	Signif. Level	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% Variance Accounted for
TPNL	0.794	.001	-4.524	0.101	47.73	.001	63.0

equivalent continuous A-weighted sound pressure level were statistically different from the remaining indices (except A-weighted sound pressure level and Perceived Noise Level) but not from themselves.

Summary of analysis of Hypothesis 6

The main conclusions to be drawn from the analysis of data for this hypothesis are:

1. The correlation coefficients for all noise indices investigated were highly significant (p= .001 level of significance). Correlation coefficients were significantly better statistically when assuming a non-linear relationship between the noise indices and mean noisiness ratings, than when assuming a linear relationship. Correcting for the presence of pure tones or discrete frequencies did not improve the correlation coefficient of Perceived Noise Level.

2. The correlation coefficient for A-weighted sound power level index was significantly worse than the correlation coefficients of the other indices investigated.

3. It is not possible to distinguish between the correlation coefficients for maximum A-weighted sound pressure level, single event noise exposure level, equivalent continuous A-weighted sound pressure level, A-weighted sound pressure level and Perceived Noise Level as they are statistically indistinguishable from each other.

4. The correlation coefficients for Perceived Noise Level and sound pressure level (linear, A-weighted and D-weighted) were indistinguishable but were statistically different from single event noise exposure level, equivalent continuous A-weighted sound pressure level and maximum A-weighted sound pressure level.

5. The percentage variance explained by the regression line was greatest for single event noise exposure level, equivalent continuous A-weighted sound pressure level and maximum A-weighted sound pressure level.

Discussion

An alternative to an A-weighted sound power level noise label for domestic appliances would therefore appear to be maximum A-weighted sound pressure level, equivalent continuous A-weighted sound pressure level or single event noise exposure level or even a combination of labels. The advantage of the sound power level label for an appliance is that the sound power level will be the same regardless of the environment in which the appliance is used. Measurements of equivalent continuous A-weighted sound pressure level, for example, will vary depending on the measurement location, but this noise index correlated well with mean noisiness ratings. (See Chapter 10, Section 10.2 for further discussion.)

8.7 Hypothesis 7

A subject's rating of annoyance evoked by an appliance will be related to some noise indices such as: L_{WA}, L_{pAav}, $L_{Aeq,30sec}$, L_{AX}, L_{Amax}, L_{pav}, L_{pDav}, *and PNL.*

As described in Chapter 6 section 6.7.2, in questionnaire 2 subjects were required to indicate how annoyed they felt when presented with different appliances, operated for 30 seconds. The categories of annoyance were:

- Not annoying at all
- A little annoying

- Moderately annoying
- Extremely annoying

The percentage of responses for each category of annoyance, and each type of appliance are given in Figure 8.6, in the form of a percentile sum plot. (The reasons for annoyance for each individual appliance are presented in Appendix R). Certain appliances were rated as 'extremely annoying', for a variety of reasons. (See Table 8.34).

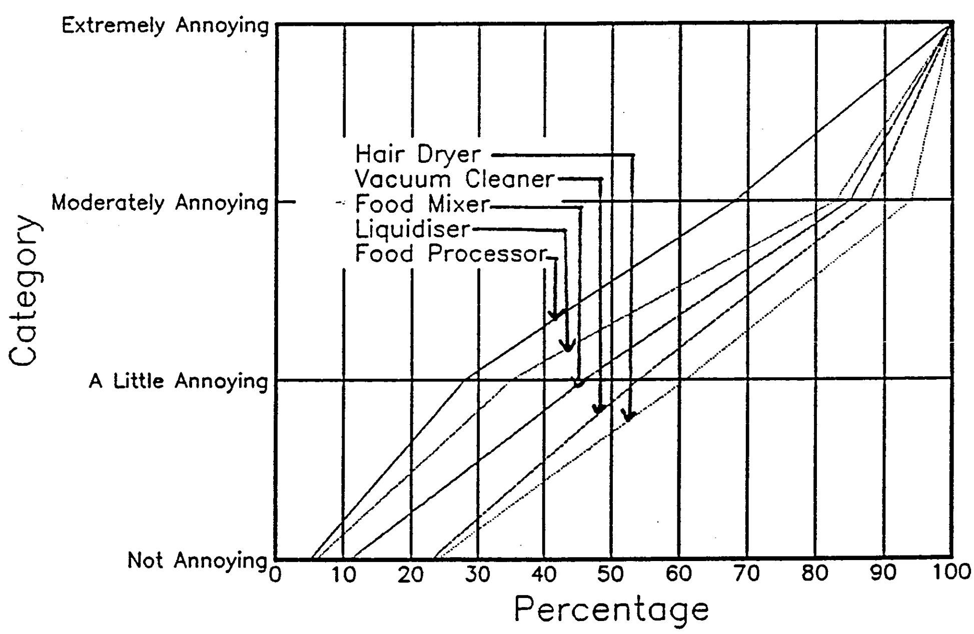


Figure 8.6 Annoyance ratings for each family of appliances - Percentile sum plot.

Table 8.34 Appliances rated as 'extremely annoying'.

Appliance	% of responses	Reasons	L_{WA}	L_{pAav}
Moulinex 722 Hair Dryer - Sp 2	16.7	2	78	72
Boots MD2 Hair Dryer - Sp 2	8.3	2	77	72
Braun 1200 Supercompact Hair Dryer - Sp 2	12.5	1,2	81	75
Ronson Hotshot Hair Dryer - Sp 2	16.7	1.2.3	82	74
Braun 1500 Compact Hair Dryer - Sp 3	4.2	2	81	73
Kerstar C606 Supreme Vacuum Cleaner	4.2	1	80	72
Electrolux 345 Vacuum Cleaner	8.3	2,3	80	72
Electrolux 350E Vacuum Cleaner - Superboost	4.2	1	82	73
Hoover 119 Vacuum Cleaner	12.5	1,5,6	91	81
Hoover U2002 Vacuum Cleaner	66.7	1,3,4	88	85
Philips HR1907 Food Mixer - Sp 1	16.7	1,2,3,5	69	67
Philips HM3060 Food Mixer - Sp 1	16.7	1,5	75	70
Kenwood Chef A901 Food Mixer - Sp 4	25	1,5	83	77
Philips TX2000 Liquidiser - Sp 1	25	1,3,5	79	76
Moulinex 530 Liquidiser	20.8	1,2	82	76
Kenwood Chef and Liquidiser	8.3	1,2	85	81
Moulinex 241.1 Liquidiser	12.5	1	84	78
Prestige L2001 Food Processor	20.8	1,2	80	69
Braun MC-1 Food Processor	62.5	1,2,3,4	87	82
Robot Chef Food Processor	12.5	1,2	85	79

where: 1= Noise level in general 2= Peaks/high frequency content of noise 3= Mixture of noise and frequency content 4= Low frequency noise 5= Complaint about a mechanical component of the appliance 6= Variation in frequency of the appliance noise

From Figure 8.6 it can be seen that there is a clear separation into the categories of appliances - the kitchen appliances were rated more annoying than hair dryers and vacuum cleaners. For example, 70% of subjects rated the food processors 'moderately annoying', wheras the same percentage of subjects rated the hair dryers 'a little annoying'.

8.8 Hypothesis 8

A subject's rating of noisiness will vary according to the family of appliances under investigation

The aim of this hypothesis was to identify a relationship between noisiness ratings and the type of appliance. Mean noisiness ratings were plotted against a variety of noise indices, for each appliance type, and regression analysis was performed to obtain regression equations and correlation coefficients.

8.8.1 Noisiness ratings vs A-weighted sound power level for each appliance type.

Regression analysis was carried out for mean noisiness ratings and A-weighted sound power level for each appliance type - see Table 8.35.

Table 8.35 Regression analysis for noisiness ratings vs A-weighted sound power level for each appliance type.

Appliance Type	r	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% variance accounted for
Hair Dryer n=11	0.677	-1.28	0.069	7.63	.025	45.9
Vacuum Cleaner n=8	0.860	-7.64	0.148	17.05	.01	74.0
Food Mixers n=4	0.756	0.88	0.05	2.57		56.3
Liquidisers n=4	-0.608	6.84	-0.020	1.18		37.0
Food Processors n=3	0.962	-13.9	0.227	12.4		92.5

The results obtained for liquidisers, food processors and food mixers are misleading and can not be compared to those of vacuum cleaners and hair dryers, as there were inadequate numbers of degrees of freedom for these appliances to allow sensible comparison of the results. Therefore, to overcome this problem, and in the light of the findings of Hypothesis 7, it was decided to combine data for hair dryers and vacuum cleaners, and to pool the data for kitchen appliances. Multiple regression analysis was carried out, assuming a non-linear relationship, as this was found to give the best fit (as discussed in Section 8.6). The results are presented in Table 8.36. Figure 8.7 presents mean noisiness ratings vs A-weighted sound power level for the combined data.

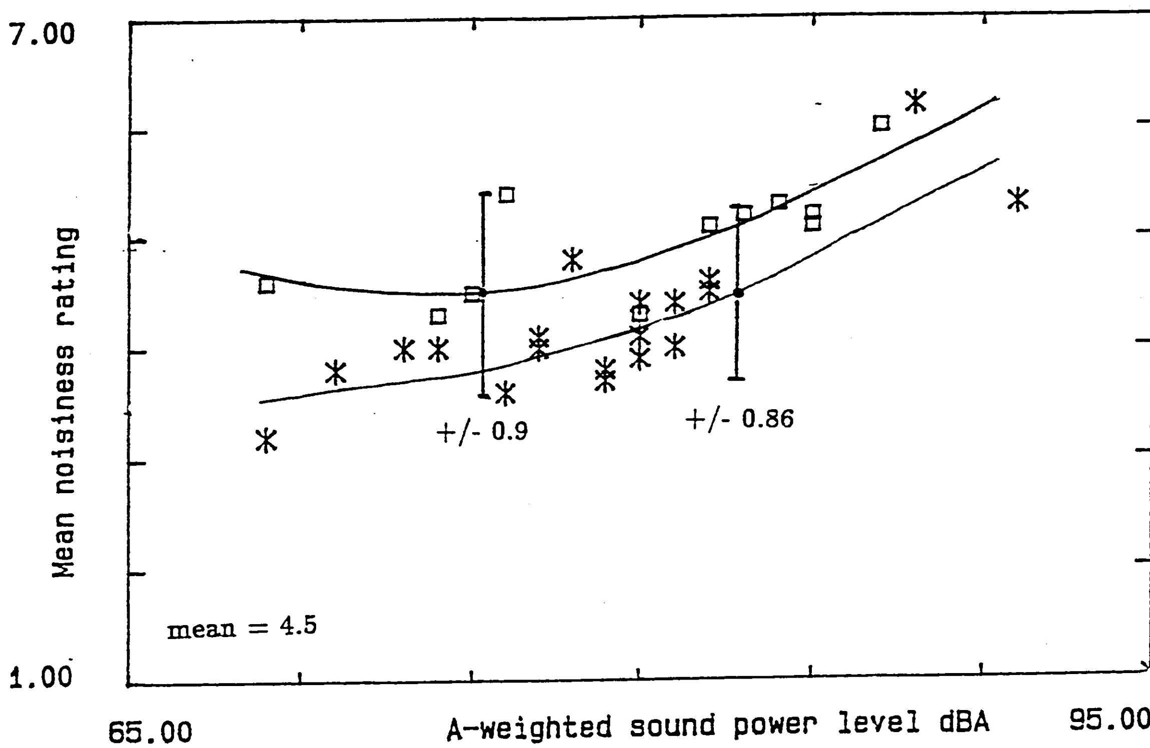
Table 8.36 Multiple regression analysis for mean noisiness ratings vs A-weighted sound power level for combined appliance types.

Appliance Combination	r	Intercept	L_{WA}	$(L_{WA})^2$	F Value	Signif. Level	% variance accounted for
HD and VC	0.818	16.5	-0.410	0.003	16.28	.001	67.0
FM LIQ and FP	0.745	37.5	-0.898	0.006	04.98	.05	55.5

From Figure 8.7, it can be seen that there is a separation into the two combinations of appliance types, suggesting that there is a relationship between family type and mean noisiness ratings. The noisiness of hair dryers and vacuum cleaners is rated lower than that of liquidisers, food mixers and food processors.

8.8.2 Discussion

If appliances are to be given a noise label consisting of the A-weighted sound power level of the appliance, then hair dryers and vacuum cleaners will be penalized. A hair dryer with a labelled A-weighted sound power level of 85 dBA may seem to be noisier than a food processor with a labelled sound power level of 80 dBA, whereas in fact, from the data presented here, it would probably be rated as less noisy. Therefore it would seem more suitable to have a separate labelling scheme for families of appliances if A-weighted



where:

asterisks represent Hair Dryers and Vacuum Cleaners

squares represent Food Mixers, Liquidisers and Food Processors

Figure 8.7 Mean noisiness ratings vs A-weighted sound power level for appliance combinations.

sound power level is to be used.

8.8.3 Noisiness ratings vs equivalent continuous A-weighted sound pressure level for each appliance type

Table 8.37 presents the regression equations for each type of appliance.

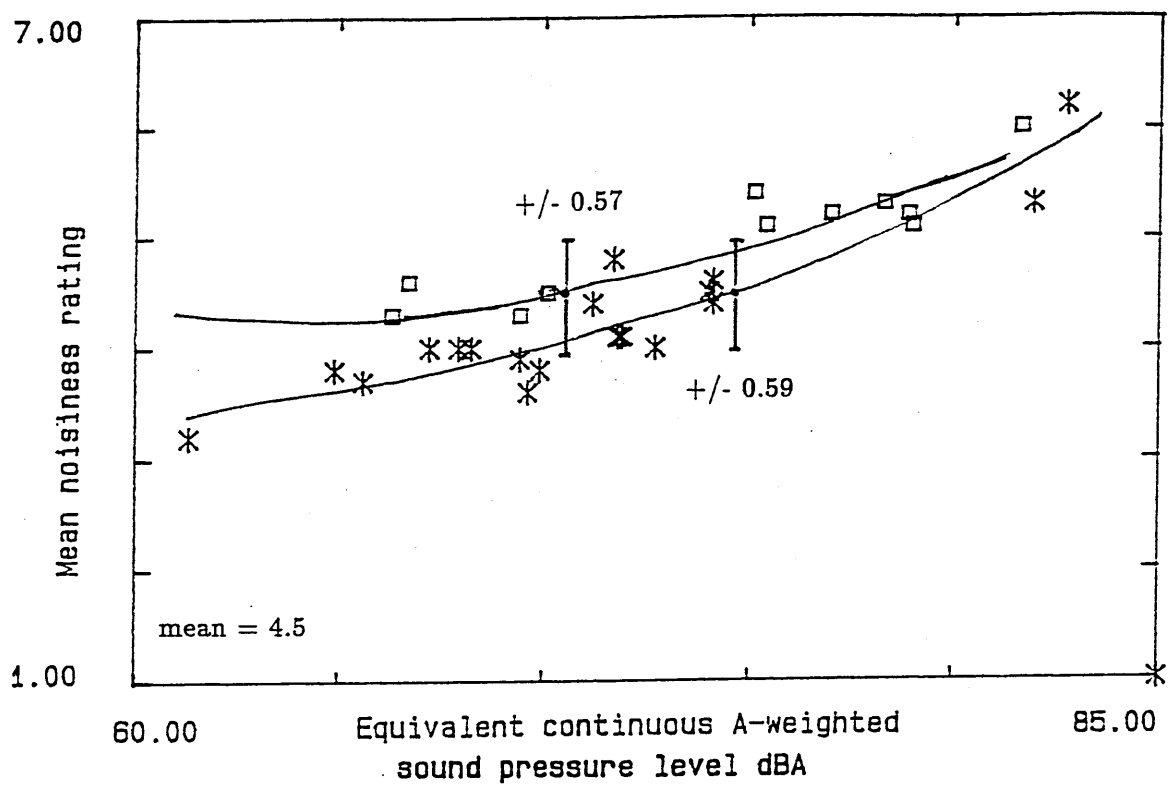
Table 8.37 Regression analysis for noisiness ratings vs equivalent continuous A-weighted sound pressure level for each appliance type.

Appliance Type	r	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% variance accounted for
Hair Dryer n=11	0.791	-2.21	0.090	15.06	.01	62.6
Vacuum Cleaner n=8	0.943	-5.47	0.136	48.46	.001	89.0
Food Mixers n=4	0.920	-0.39	0.072	11.04		84.7
Liquidisers n=4	-0.010	5.75	0.001	0.002		1.0
Food Processors n=3	0.938	-4.39	0.124	7.33		88.0

Again, insufficient numbers of degrees of freedom for the kitchen appliances meant that the data could not sensibly be compared with that for vacuum cleaners and hair dryers. Therefore the data for hair dryers and vacuum cleaners was combined and the data for kitchen appliances was pooled. Multiple regression analysis was carried out and the results are presented in Table 8.38. Figure 8.8 presents mean noisiness ratings vs equivalent continuous A-weighted sound pressure level for the combined data.

Table 8.38 Multiple regression analysis for mean noisiness ratings vs equivalent continuous A-weighted sound pressure level for combined appliance types.

Appliance Combination	r	Intercept	$L_{Aeq,30sec}$	$(L_{Aeq,30sec})^2$	F Value	Signif. Level	% variance accounted for
HD VC	0.920	12.0	-0.330	0.003	43.91	.001	84.6
FM LIQ FP	0.906	17.6	-0.435	0.004	18.4	.01	82.2



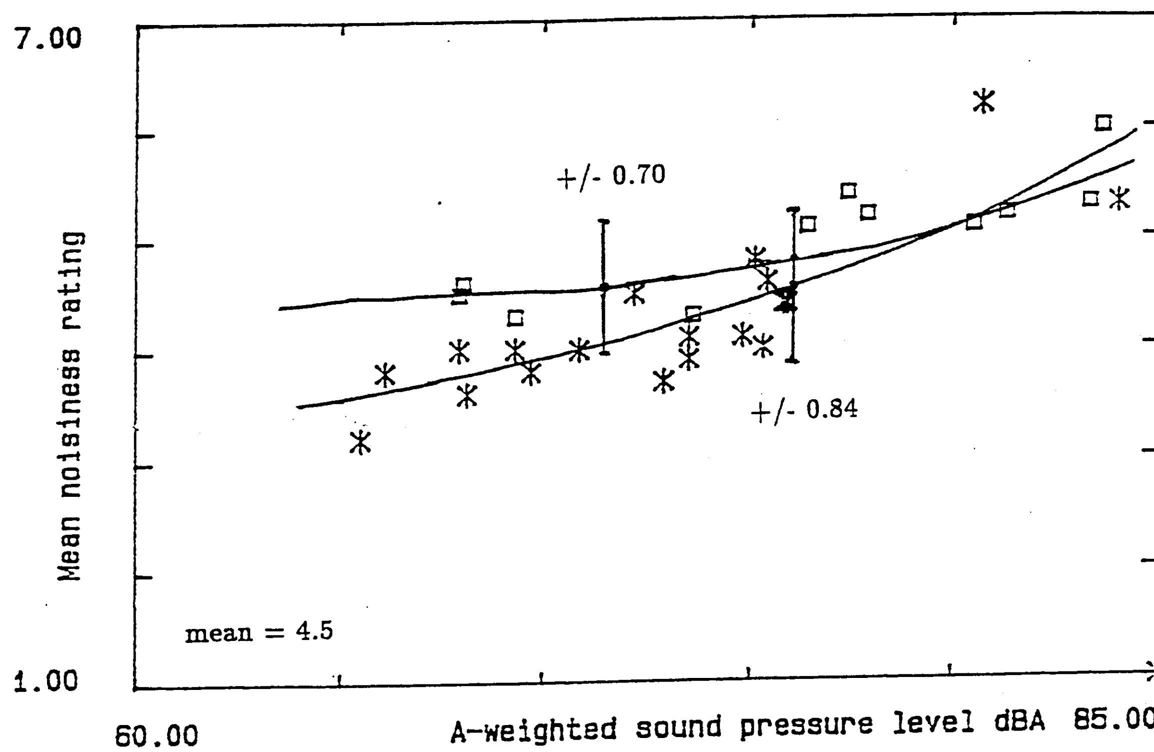
where:

asterisks represent Hair Dryers and Vacuum Cleaners

squares represent Food Mixers, Liquidisers and Food Processors

Figure 8.8 Mean noisiness ratings vs equivalent continuous A-weighted sound pressure level for appliance combinations.

Visual examination of Figure 8.8 reveals that the relationship between appliance type and noisiness ratings is less pronounced than for A-weighted sound power level. Indeed, visual examination of the same data for A-weighted sound pressure level also reveals a less pronounced separation of appliance types - see Figure 8.9.



where:

asterisks represent Hair Dryers and Vacuum Cleaners

squares represent Food Mixers, Liquidisers and Food Processors

Figure 8.9 Mean noisiness ratings vs A-weighted sound pressure level for appliance combinations.

Therefore the results obtained for A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level do not support the finding as for A-weighted sound power level, and suggests that a single relationship can be used to represent the data.

8.8.4 Summary of analysis of Hypothesis 8

The results that can be drawn from the analysis are:

- The strength of the relationship between appliance type and noisiness ratings was dependent on the noise index with which the ratings were correlated. A separation into appliance types was apparent when mean noisiness ratings were correlated with A-weighted sound power level, but not when correlated with A-weighted sound pressure level or equivalent continuous A-weighted sound pressure level.

- In terms of labelling, these results suggest that A-weighted sound power level label, as recommended by the EEC [21], is not the best choice when considering a correlation with subjective response to noise. It is therefore suggested that it would be more consistent to use equivalent continuous A-weighted sound pressure level for the label, as measured at the user's ear.

Hypotheses relating different subjective ratings to each other

8.9 Hypothesis 9

A subject's rating of the noisiness of an appliance will be determined by the rating of annoyance evoked by the appliance noise

If there were to be a relationship between ratings of noisiness and of annoyance, one might expect that the appliance would be rated more annoying as it was rated noisier. Fewer subjects would rate the appliance 'not annoying' as the noisiness increased. Table 8.39 presents the percentage of respondents in each category for each type of appliance. This information, for each individual appliance is presented in Appendix S. The noisiness rating scale comprised seven categories, but because of empty categories, the following combinations were made:

- 1,2,3 were combined and have been classified as 'not noisy' for this analysis.
- 4 was classified as 'quite noisy'
- 5 was classified as 'moderately noisy'
- 6,7 were combined and have been classified as 'very noisy'

The annoyance scale included four rating categories, ranging from 'not annoying at all' to 'extremely annoying'. Categories were combined since some were empty.

- 'Not annoying at all' and 'A little annoying' were combined and classified as 'not annoying' for this analysis.
- 'Moderately annoying' and 'Extremely annoying' were combined and classified as 'extremely annoying'.

From Table 8.39 it can be seen that for each appliance type, there is a relationship between noisiness and annoyance ratings. As the appliances are rated noisier, so the percentage of responses for 'not annoying' decreases and there is a prominent increase in the percentage of responses for 'extremely annoying'. For example, of the subjects who rated hair dryers 'not very noisy', 81% also rated them 'not annoying'. However of the subjects who rated hair driers 'very noisy', only 5% rated them 'not annoying'.

To determine whether there is a valid relationship between noisiness and annoyance ratings for all appliances, log linear analysis was carried out (which aims to establish relationships between categorical data). For this analysis, the categories of noisiness were further combined to create just two categories of noisiness (because of empty cells in a matrix of annoyance and noisiness). Noisiness ratings 1,2,3,4 were combined, as were 5, 6, and 7. The resultant Z values for each group of appliances can be seen in Table 8.40

In each case the Z value exceeds 1.96. Although the data for group 3 appliances fits the model enough to demonstrate a relationship, the relationship for this group is not as strong as for the other four groups.

Table 8.39 Percentage of responses in each category of noisiness and annoyance for all types of appliances.

Noisiness	Not annoying	Extremely annoying
Hair Dryers		
Not noisy	81.0	19.0
Quite noisy	63.6	36.4
Moderately noisy	45.2	54.8
Very Noisy	5.0	95.0
Vacuum Cleaners		
Not noisy	83.8	16.1
Quite noisy	55.6	44.4
Moderately noisy	51.1	48.9
Very noisy	8.1	91.9
Food Mixers		
Not noisy	76.5	23.5
Quite noisy	64.5	35.5
Moderately noisy	30.0	70.0
Very noisy	16.7	83.3
Liquidisers		
Not noisy	100	00.0
Quite noisy	61.9	38.1
Moderately noisy	32.6	67.4
Very noisy	16.7	83.3
Food Processors		
Not noisy	57.1	42.9
Quite noisy	53.3	46.7
Moderately noisy	40.0	60.0
Very noisy	00.0	100.0

Table 8.40 Z Values from Log Linear Analysis of each group of appliances.

Group	Z Value
1	5.528
2	3.525
3	1.962
4	2.092
5	3.671

It can be concluded that over all appliances in these particular experiments, there is a relationship between ratings of noisiness and annoyance. However, this relationship could conceivable be linked to a common factor - namely change in noise level. It has been demonstrated in the analysis of hypotheses 6 and 7 that noisiness and annoyance ratings can be correlated with measures of noise (in the form of various indices), with highly significant results. Therefore, the relationship between noisiness and annoyance ratings probably reflect their relationship with the change in noise level.

8.10 Hypothesis 10

A subject's rating of the noisiness of an appliance will be related to an appraisal of the usefulness of that appliance.

If there were to be a relationship between an appraisal of usefulness of an appliance and its noisiness rating, one might expect that noisiness ratings for appliances rated 'moderately' or 'extremely useful' would be less than those where the appliance was rated 'not useful' or 'a little useful'. There may be a linear relationship between noisiness ratings and the ratings of usefulness. In Table 8.41 the mean noisiness rating for each category of usefulness is presented, for each appliance type. (See Appendix T for information relating to each individual appliance).

Table 8.41 Mean noisiness rating for each category of usefulness for all appliance types.

Appliance	Not Useful	A Little	Moderately	Extremely
Hair Dryer	3.37	4.2	3.9	3.9
Vacuum Cleaner	5.67	4.9	4.4	4.4
Food Mixer	4.625	4.37	4.595	5.0
Liquidiser	4.7075	5.225	5.1325	5.75
Food Processor	4.93	5.027	5.027	5.17
MEAN	4.6605	4.7444	4.6109	4.844

Examination of Table 8.41 reveals that there is no obvious relationship between the noisiness rating given to a domestic appliance and an appraisal of usefulness of the appliance. With the exception of vacuum cleaner ratings, the lowest mean noisiness rating was usually associated with the category 'not useful' or 'a little useful'. Thus it can be concluded that there is no relationship between a subject's rating of the noisiness of an appliance and their appraisal of the usefulness of that appliance.

8.11 Hypothesis 11

A subject's appraisal of the usefulness of an appliance will be related to a rating of the acceptability of the noise of the appliance.

If there were to be a relationship between an appraisal of the usefulness of an appliance and the acceptability rating of its noise, one might expect that the more useful the appliance was rated, the more likely it should be that the noise is considered to be acceptable. Therefore the percentage of responses in the category of 'extremely useful' and 'acceptable' should be larger than for 'not useful' and 'acceptable'. Conversely, the percentage of responses in the category 'not useful' and 'not acceptable' should be larger than 'extremely useful' and 'not acceptable'. In Table 8.42 the percentage of responses to categories of usefulness and acceptability for each appliance type are given. (The information for each individual appliance is presented in Appendix U). Originally, there were four categories comprising usefulness which were:

1. Not at all useful
2. A little useful
3. Moderately useful
4. Extremely useful

When testing this hypothesis it was necessary to combine components 1 and 2, and 3 and 4, due to empty categories in the matrix of usefulness and acceptability which made analysis difficult.

Table 8.42 Percentage of responses to categories of usefulness and acceptability for each type of appliance.

Usefulness	Acceptable	Not Acceptable
Hair Dryers		
Not useful	65.5	34.5
Extremely useful	83.0	17.0
Vacuum Cleaners		
Not useful	65.0	35.0
Extremely useful	84.0	16.0
Food Mixers		
Not useful	67.0	33.0
Extremely useful	71.0	29.0
Liquidisers		
Not useful	62.0	38.0
Extremely useful	63.0	37.0
Food Processors		
Not useful	56.0	44.0
Extremely useful	61.0	39.0

Examination of Table 8.42 reveals that there is no relationship across all appliances - the relationship seems to be dependent on appliance type. Ratings of usefulness of food processors, liquidisers and food mixers had no effect on the percentage of responses for 'acceptable' or 'not acceptable'. The percentages are very similar. However, acceptability of the noise of hair dryers and vacuum cleaners improved with improved ratings of usefulness.

The lack of a clear and consistent relationship for all appliances is reflected in the Z values of log linear analysis, as presented in Table 8.43.

There appears to be a relationship between usefulness and acceptability ratings for only Groups 1 and 4. It can be concluded from this study, that there is no consistent relationship between an appraisal of usefulness and the rating of acceptability of the appliance noise.

Table 8.43 Z Values from Log Linear Analysis of each group of appliances.

Group	Z Value
1	-3.09537
2	-1.55962
3	-1.13027
4	-2.01483
5	-0.09856

8.12 Hypothesis 12

A subject's rating of the noisiness of an appliance will be determined by the subject's rating of the acceptability of the noise of the appliance.

If there were to be a relationship between noisiness ratings and the acceptability of the noise of the appliance, one might expect that as the noisiness rating increases from 1 to 7, the number of subjects finding the appliance noise acceptable becomes less. So, appliance noises with high noisiness ratings should also be considered unacceptable. Alternatively, appliance noises with low noisiness ratings should be considered acceptable.

To investigate this hypothesis, various categories of the noisiness rating scale were combined as follows;

- ratings of 1,2,3 were combined and classified 'not noisy' for this analysis
- ratings of 4 were classified as 'quite noisy'
- ratings of 5 were classified as 'moderately noisy'
- ratings of 6 and 7 were combined and classified 'very noisy'

Table 8.44 presents the percentage of the respondents in each category. The information for each individual appliance is presented in Appendix V

It is apparent that for hair dryers, vacuum cleaners and food mixers, the relationship holds true, and it can be seen that for increasing noise ratings, the percentage of respondents rating the noise 'acceptable' is decreasing

Table 8.44 Percentage of responses in each category of noisiness and acceptability for all types of appliances.

Noisiness	Acceptable	Not acceptable
Hair Dryers		
Not noisy	88.6	11.4
Quite noisy	81.1	18.9
Moderately noisy	69.4	30.6
Very Noisy	15.8	84.2
Vacuum Cleaners		
Not noisy	98.2	1.8
Quite noisy	90.7	9.3
Moderately noisy	77.8	22.2
Very noisy	48.6	51.4
Food Mixers		
Not noisy	100.0	00.0
Quite noisy	83.9	16.1
Moderately noisy	60.0	40.0
Very noisy	27.8	72.2
Liquidisers		
Not noisy	50.0	50.0
Quite noisy	85.7	14.3
Moderately noisy	65.1	34.9
Very noisy	43.3	56.7
Food Processors		
Not noisy	71.4	28.6
Quite noisy	93.3	6.7
Moderately noisy	61.5	38.5
Very noisy	29.2	70.8

(and consequently the percentage finding the noise level 'not acceptable' is increasing with increasing noisiness ratings). For food processors and liquidisers, the relationship holds true with the exception of the 'not noisy' category, in which there were few responses. To establish whether the relationship is valid for all appliances, log linear analysis was performed. Categories of noisiness were further combined due to empty categories, so that 1,2,3,4 were combined, as were 5,6,and 7. The resultant Z values for each group of appliances is presented in Table 8.45.

Table 8.45 Z Values from Log Linear Analysis of each group of appliances.

Group	Z Value
1	4.458
2	2.938
3	2.507
4	2.626
5	2.677

It can be concluded that, for the appliance noises presented in this particular experiment, there is a relationship across all appliances, between ratings of noisiness and acceptability.

8.13 Hypothesis 13

A subject's rating of annoyance evoked by an appliance will be related to the subject's rating of the acceptability of the noise of the appliance.

If there were to be a relationship between a rating of annoyance and the acceptability of the noise of an appliance, one might expect that the higher the annoyance ratings, the less acceptable the appliance noise would be to the subject. Table 8.46 shows the percentage of responses in each category of annoyance and acceptability for the different appliance types. (The information for each individual appliance is presented in Appendix W). The annoyance rating scale was comprised of four categories:

1. Not annoying at all

2. A little annoying

3. Moderately annoying

4. Extremely annoying

The presence of empty categories again meant that components 1 and 2, and 3 and 4 were combined.

Table 8.46 Percentage of responses in each category of acceptability and annoyance for all types of appliances.

Annoyance	Acceptable	Not Acceptable
Hair Dryers		
Not annoying	91.4	8.6
Extremely annoying	49.5	50.5
Vacuum Cleaners		
Not annoying	99.0	1.0
Extremely annoying	62.0	38.0
Food Mixers		
Not annoying	89.0	11.0
Extremely annoying	51.0	49.0
Liquidisers		
Not annoying	85.0	15.0
Extremely annoying	50.0	50.0
Food Processors		
Not annoying	90.0	10.0
Extremely annoying	46.0	54.0

Examination of Table 8.46 reveals for the 'not acceptable' category the percentage of subjects who rated the appliance 'extremely annoying' is always greater than those who rate the appliance 'not annoying'. For example, only 1% of the subjects who rated vacuum cleaners 'not annoying', also rated the noise level 'not acceptable'. However 38% of the subjects who rated the vacuum cleaners 'extremely annoying', rated the noise level 'not acceptable'. Conversely, of the subjects who found the appliance 'acceptable', the percentage who rated the appliance as 'not annoying' is always greater than those who rated it 'extremely annoying'. 90% of the subjects who rate food processors 'not annoying', also found the noise level 'acceptable'. However, 46% of the subjects who rated the appliance 'extremely annoying' also found the noise level acceptable.

There appears to be a relationship between ratings of the acceptability of the appliance noise and annoyance ratings. To investigate if this relationship is significant across all appliances a log linear analysis was carried out on the individual groups of data. (see Chapter 7, section 7.1.10 for explanation of this test). The Z values for each group of appliances is shown in Table 8.47.

Table 8.47 Z Values from Log Linear Analysis of each group of appliances.

Group	Z Value
1	4.98323
2	3.71747
3	3.55501
4	4.00339
5	3.94725

Since all Z Values exceeded 1.96, it can be concluded that there is a relationship between ratings of annoyance and acceptability ratings for the appliances investigated in these experiments.

8.14 Hypothesis 14

A subject's appraisal of the usefulness of an appliance will be related to the rating of annoyance evoked by the appliance noise.

If there were to be a relationship between a subject's appraisal of the usefulness of an appliance and the annoyance rating evoked by the appliance noise, one might expect that for appliances rated 'moderately' or 'extremely useful', subjects would also rate them 'not at all annoying' or 'a little annoying'. Alternatively, for appliances rated 'not very useful', then one might expect that they would also be rated 'moderately' or 'extremely annoying'. In Table 8.48 the percentage of responses for each category of usefulness and acceptability, and for each type of appliance are presented. The information for each individual appliance is given in Appendix X. Annoyance and usefulness rating scales comprised the following categories:

1. Not very useful/Not at all annoying

2. A little useful/a little annoying

3. Moderately useful/moderately annoying

4. Extremely useful/extremely annoying

Because some cells of the matrix of usefulness and annoyance were empty, categories 1 and 2, and 3 and 4 were combined.

Table 8.48 Percentage of responses in each category of usefulness and annoyance for all types of appliances.

Usefulness	Not very annoying	Extremely annoying
Hair Dryers		
Not very useful	47.9	52.1
Very useful	73.1	26.9
Vacuum Cleaners		
Not very useful	50.0	50.0
Very useful	54.1	45.9
Food Mixers		
Not very useful	58.3	41.7
Very useful	35.4	64.6
Liquidisers		
Not very useful	34.5	65.5
Very useful	36.8	63.2
Food Processors		
Not very useful	29.3	70.7
Very useful	25.8	74.2

Examination of Table 8.48 reveals that there is no consistent relationship for all the appliances. A larger percentage of the subjects who rated the food mixers 'not very useful' or 'a little useful', also rated them as 'not very annoying'. Moreover, a greater percentage of the subjects who rated food mixers, liquidisers and food processors 'moderately' or 'very useful', also rated them as 'extremely annoying'.

Log linear analysis was performed on this data, and examination of the resultant Z values confirmed the relationship - there was no consistent relationship for all appliances. (See Table 8.49)

Table 8.49 Z Values from Log Linear Analysis of each group of appliances.

Group	Z Value
1	-3.09537
2	-1.55962
3	-1.13027
4	-2.01483
5	-0.09856

It can be concluded that there is no consistent relationship between a subject's rating of the usefulness of an appliance and the ratings of annoyance.

8.14.1 Discussion

One of the major aims of this study was to identify the noise index that would show the highest correlation with a subjective reaction to domestic appliance noise. In assessing this question, however, another emerges - namely which subjective rating scale is the most consistent when correlated with the variety of noise indices?

The rating scales under investigation were: noisiness, annoyance and acceptability. (Although ratings of usefulness were investigated, usefulness is an appraisal that is not related to the noise output of the appliance.) The acceptability and annoyance rating scales consisted of verbal responses (unlike the noisiness rating scale, whose responses were numerical) which meant scores had to be assigned to each category.

The following scores were assigned to the annoyance rating scale:

Not annoying at all = 1

A little annoying = 2

Moderately annoying = 3

Extremely annoying = 4

These scores were assigned to the responses and, for each appliance, the mean scores were obtained and correlated with the various noise indices.

High correlations were achieved for the acceptability rating scale by simply using the number of responses for each category of the acceptability rating scale - eg. the total number of people who said the noise was not acceptable. Therefore, the total 'not acceptable' responses for each appliance were correlated against the various noise indices.

A numerical scale already existed for the noisiness rating scale so the mean noisiness rating was obtained for each appliance and correlated with the various noise indices.

Table 8.50 8.51 and 8.52 present the correlation coefficients of each rating scale against the various noise indices, and the regression equations obtained.

Table 8.50 Correlation coefficients and regression equations - Noise indices vs annoyance ratings.

Index	r	Signif. Level	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% variance accounted for
L_{WA}	0.574	.05	-1.64	0.05	13.73	.001	32.9
L_{pAav}	0.748	.001	-2.20	0.06	35.68	.001	56.0
$L_{Aeq,30sec}$	0.754	.001	-2.4	0.07	36.87	.001	56.8
L_{Amax}	0.754	.001	-2.54	0.07	36.78	.001	56.8
L_{AX}	0.739	.001	-3.36	0.07	33.66	.001	54.6
L_{pav}	0.656	.001	-1.02	0.05	13.38	.01	32.3
L_{pDav}	0.569	.05	-2.24	0.06	24.42	.001	46.6
PNL	0.683	.001	-3.13	0.06	21.14	.001	43.0

It can be seen that each rating scale correlates significantly (at least p=.05) with each noise index (see column 3 in each Table). With the an-

Table 8.51 Correlation coefficients and regression equations - Noise indices vs acceptability ratings.

Index	r	Signif. Level	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% variance accounted for
L_{WA}	0.315	.05	-12.2	0.234	3.09		9.9
L_{pAav}	0.556	.01	-22.0	0.391	12.55	.01	30.9
$L_{Aeq,30sec}$	0.551	.01	-23.0	0.406	12.2	.01	30.4
L_{Amax}	0.530	.01	-22.6	0.394	10.97	.01	28.1
L_{AX}	0.519	.01	-27.3	0.385	10.32	.01	26.9
L_{pav}	0.266	.05	-7.05	0.176	2.15		7.1
L_{pDav}	0.531	.01	-24.1	0.376	11.0	.01	28.2
PNL	0.463	.05	-26.2	0.373	7.67	.025	21.5

Table 8.52 Correlation coefficients and regression equations - Noise indices vs noisiness ratings.

Index	r	Signif. Level	Intercept Coeffic.	Slope Coeffic.	F Value	Signif. Level	% variance accounted for
L_{WA}	0.687	.001	-2.785	0.093	25.05	.001	47.2
L_{pAav}	0.815	.001	-3.644	0.110	55.3	.001	66.4
$L_{Aeq,30sec}$	0.882	.001	-3.950	0.117	98.51	.001	77.8
L_{Amax}	0.874	.001	-4.120	0.117	10.61	.001	76.4
L_{AX}	0.877	.001	-5.770	0.118	93.43	.001	77.0
L	0.762	.001	-2.407	0.091	38.88	.001	58.1
L_{pDav}	0.808	.001	-4.159	0.107	52.6	.001	65.3
PNL	0.795	.001	-5.565	0.115	47.93	.001	63.1

noyance rating scale the correlation coefficient was highest for equivalent continuous A-weighted sound pressure level and maximum A-weighted sound pressure level indices. The highest correlation coefficient on the acceptability rating scale was achieved by A-weighted sound pressure level, and by equivalent continuous A-weighted sound pressure level on the noisiness rating scale. From examination of the correlation coefficients it would seem that all scales performed well. However, from examination of the regression equations, particularly the column headed '% variance accounted for', it is possible to determine the most consistent scale. The percentage of variance is a measure of how well the fitted regression equation explains the variance observed in the data. Just over half the variance is explained by the fitted regression equation for the annoyance rating scale. At most, only 30 % of the variance is explained for the acceptability rating scale. However,77.8% of the variance observed is explained by the regression equation of the noisiness rating scale. Thus it is possible to conclude that the noisiness rating scale is the most consistent of the subjective rating scales examined in the study.

8.15 Summary

In this chapter the analysis of the objective and subjective experimental data have been presented. The conclusions to be drawn from this chapter are as follows:

1. The subjects' ratings of the noisiness of domestic appliances varied with the presentation of appliance noises with differing physical characteristics, although there was no significant difference between noisiness ratings of the vacuum cleaner and food processor in this experiment.

2. Subjects' ratings of noisiness depended on whether the subject was using the appliance or listening to it. However, this difference was not observed to be consistent for all appliances. There was no significant difference between noisiness ratings of the hair dryer and liquidiser either when the subject used or listened to the appliances. Noisiness

ratings were higher while subjects were listening to the vacuum cleaner being operated rather than when using it. This was attributed to the presence of a discrete frequency at 250 Hz in the listener position. However, noisiness ratings were higher while the subject was operating the food processor than when listening to it. This was attributed to the higher A-weighted sound pressure levels in the user position for each one-third octave centre frequency.

3. Subjects' rating of noisiness appeared to be conditioned by the duration of operation of the appliance. However, the results were not straightforward. When the appliances were presented for 15 seconds in the first session and 30 seconds in the second session, noisiness ratings increased from session 1 to session 2, suggesting that elongation of exposure to appliance noise increased noisiness ratings. However, in a follow-up experiment, where 2 appliances were presented for 30 seconds in the first session and 15 seconds in the second session, the noisiness ratings were not statistically different from each other.

4. Mean noisiness ratings did not vary in a way that was comparable to the magnitude of A-weighted sound power levels.

5. Subjects' ratings of noisiness correlated highly with several noise indices - in particular, ratings of noisiness correlated highly with equivalent continuous A-weighted sound pressure level, single event noise exposure level and maximum A-weighted sound pressure level. It was not possible to say which of these three indices was the most successful as they were shown to be indistinguishable from each other statistically and from A-weighted sound pressure level. The addition of corrections for the tonal content of the noise did not improve the correlations.

6. Subjects' ratings of annoyance were found to depend on the family of appliances under investigation. Hair dryers and vacuum cleaners were rated less annoying than the kitchen appliances - food mixers, food processors and liquidisers.

7. Subjects' ratings of noisiness also varied according to the family of appliances under investigation. However, the strength of this relationship was dependent on the noise index with which the noisiness ratings were correlated. Noisiness ratings for kitchen appliances as a group were generally higher than noisiness ratings for hair dryers and vacuum cleaners, even when they produced similar A-weighted sound power levels. Therefore an A-weighted sound power level label will be misleading to consumers whose choice is noise-dependent and a separate labelling scheme for different families of appliances would be an advantage. However, the relationship was less obvious when noisiness ratings were correlated with A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level and a single labelling scheme for all appliance types would be applicable.

8. There were found to be consistent relationships between subjects' ratings of the noisiness and annoyance of an appliance noise. As ratings of noisiness increased from 1 to 7, so the annoyance rating increased. However this relationship is considered to be linked to a common factor - change in noise level. Both of these subjective reactions showed significant correlations with various noise indices.

9. There were no consistent relationships found between subjects' appraisals of the usefulness of an appliance and a rating of the acceptability of the noise of the appliance.

10. There were found to be consistent relationships between ratings of the noisiness and of the acceptability of the noise of the appliance. As ratings of noisiness increased from 1 to 7, so ratings of acceptability decreased.

11. There were no consistent relationships between an appraisal of the usefulness of an appliance and the acceptability of the noise of an appliance.

12. There were found to be consistent relationships between ratings of annoyance evoked by an appliance noise and those of acceptability of the noise. As appliances were rated as more annoying, so the noise was also rated as less acceptable.

13. There were no consistent relationships between appraisals of the usefulness of an appliance and ratings of the annoyance evoked by the appliance noise.

14. When the correlation coefficients and results of regression analysis for the three subjective rating scales were compared, it was found that the noisiness rating scale provided the most consistent correlation with the several noise indices.

Although all the factors discussed in this summary are important, the most important findings that warrant further investigation are:

- A-weighted sound power level label, on it own, is not considered to be the most appropriate choice for labelling domestic appliances because of the separation of noisiness ratings into appliance types.

- Mean noisiness ratings were conditioned by the duration of operation of the appliance.

Chapter 9

Contribution of domestic appliance noise to an individual's daily noise dose

9.1 Introduction

In Chapter 2, section 2.5 a study carried out for the Environmental Protection Agency [7] was discussed. The amount and effect of domestic appliance noise exposure in homes in the United States was assessed. The study covered the following areas:

1. the distribution of appliances over family units
2. the time that the appliances were typically in use
3. the exposure of people who are in the home.

Using this data they were able to arrive at the following conclusions:

1. The appliances (Group I appliances) to which people were exposed for the greatest lengths of time in the home environment included refrigerators, fans, air conditioners, clothes dryers and freezers. Such appliances had a widespread distribution throughout households. Fortunately, they were the least noisy of the appliances in the home. The effect of exposure to such appliances was usually speech interference in the vicinity of the appliance.

2. Group II appliances, including vacuum cleaners, dishwashers, food mixers, hair dryers and electric knives, were found in many American homes, although not all the sources were as common as found in Group I. The major effect of exposure to the noise of these appliances was speech interference. Communication during their operation was found to be difficult. Typically, however, these appliances were used for brief periods, thus the consequence of exposure was temporary interruption of conversation. The most significant indirect effect was annoyance.

3. Appliances included in Group III, sewing machines, electric shavers, food blenders, food disposers, and electric mowers, were the noisiest, but found in fewer homes than Group II appliances. Usually, exposure to their noise was for brief periods. The major effect of exposure experienced by individuals in their vicinity was speech interference. Operators did not attempt conversation during the periods in which the appliances were used, although communication by shouting was still possible. Also, annoyance was an indirect effect of exposure as the operators found the noise to be unpleasant, particularly when it contained pure tone components or had a highly variable distribution of noise levels.

Exposure to domestic appliance noise in homes in the United Kingdom is also widespread. From the results of Questionnaire 1 (presented in Appendix I) the following observations were made regarding the extent of exposure to domestic appliance noise and respondents' feelings about such noise:

1. Over half of the thirty-two subjects completing the questionnaire possessed the following appliances: food mixer, food processor, hair dryer, kettle, liquidiser, sewing machine, shaver, vacuum cleaner and washing machine.

2. The most frequently used appliances were hair dryers, kettles, vacuum cleaners and washing machines. With the exception of kettles, these

appliances would be classified among Group II appliances according to EPA classifications.

3. Although appliances were liked for their efficiency/time saving qualities and convenience, the most frequently cited reasons for disliking an appliance were noise and bad design.

4. When asked if they were prepared to put up with the noise of their most frequently used appliances, the answers were very varied along the 7 point rating scale from 1 - 7 (not willing to very willing). For example, in the case of subjects who frequently used a vacuum cleaner, the responses were:

Not willing	% of total response
1	11.1
2	19.5
3	14.8
4	14.8
5	14.8
6	5.5
7	19.5
Very willing	

5. When asked whether the noise from domestic appliances ever bothered or annoyed them, the responses were:

	% of responses
Very much	18.8
Moderately	40.6
A little	31.3
Not at all	9.4

Over half of the subjects were at least moderately annoyed by the noise.

6. When asked to calculate how many hours per week they spent inside their home (i.e. in the environment of domestic appliance noise), more than 50% replied that they spent at least 90 hours inside the home.

From the results of this small survey, domestic appliance noise seems to be a source of annoyance for the majority of respondents, and ownership of the noisy domestic appliances was quite common. Knowing this, one might then question the extent to which domestic appliance noise contributes to an individual's 24 hour noise dose. From the EPA study, it is possible to assess the effect and extent of exposure to domestic appliance noise. However the information provided could not allow an assessment to be made of the *contribution of domestic appliance noise to an individual's 24 hour noise exposure.* The aim of this chapter is to make such an investigation.

9.2 Method

To assess the contribution of domestic appliance noise to an individual's 24 hour noise exposure requires three kinds of information:

1. Measurements of equivalent continuous A-weighted sound pressure level of typical activities during a 24 hour period ($L_{Aeq,24hour}$).
2. Noise levels emitted by domestic appliances in typical locations within the home.
3. Details regarding how individuals use their time.

The latter two sources of information allow the extension of the results of the former to a more general population. Each of these items will be discussed in turn.

9.2.1 Measurement of L_{Aeq} of typical activities during a 24 hour period

Information which was generated by Open University students as part of their study of a second level course T234 Environmental Control and Public

Health, was used to assess the contribution of domestic appliance noise to an individual's total noise dose during a typical 24 hour period. As part of their studies, the students were issued with type 3 integrating sound level meters, and were required to measure the equivalent continuous A-weighted sound pressure level of activities they are involved in during a typical 24 hour period. They recorded both the duration of the sample measurement period and the duration of the activity. The reliability and accuracy of this data has been tested rigorously, as described elsewhere [122]. Equivalent continuous A-weighted sound pressure level (24 hours) is calculated for each student and the percentage of the corresponding total energy, contributed by domestic appliance noise, is assessed. The equation for calculating the 24 hour equivalent continuous A-weighted sound pressure level is:

$$L_{Aeq,24hour} = 10\, log \frac{1}{T}[t1\; antilog\, \frac{L1}{10} + t2\; antilog\, \frac{L2}{10} + \ldots\ldots\ldots] \qquad (9.1)$$

where *t1* is the time for which the sound level is *L1*, and so on. *T* is the total time period, which in the present study is 24 hours.

Table 9.1 shows for male and female students, the percentage of the total energy (corresponding to 24 hour noise exposure) contributed by domestic appliance noise. The percentage is systematically greater for female students (42% on average) compared with 22% for male students. Among the various occupations, the percentage of 24 hour dose contributed by domestic appliances is greatest for housewives, teachers and retired people who spent most of their day in the home. The results for teachers reflects the seasonal nature of the Open University course as they study during the vacation period.

However, this data becomes more meaningful when the sound levels experienced when using domestic appliances are converted into a level equivalent to an 8 hour daily noise exposure using the following formula:

$$10log_{10}\frac{1}{8x60}\left[t1antilog\frac{L1}{10} + t2antilog\frac{L2}{10}\ldots\right] \qquad (9.2)$$

where:

8 x 60 represents 8 hours in minutes

Table 9.1 The percentage of the total energy (corresponding to 24 hour noise exposure) as contributed by domestic appliance noise.

	Male			Female		
Occupation	Range	Average	No.	Range	Average	No.
Housewife				0.3-97.5	46.1	21
Armed Forces	0.8 - 16.6	11.4	4			
Admin./manager	20.2	20.2	1	0.4	0.4	1
Teachers	2.3 - 97.5	48.3	6	23.0 - 92.8	64.4	6
Medical, social	4.9 - 80.9	30.5	3	0.5 - 48.8	17.3	7
Qualified scientist and eng.	0.1 - 41.7	9.1	7	0.8 - 99.1	35.9	8
Technical personnel	0.3 - 48.7	10.6	27	0.8 - 99.1	35.9	8
Electrical, electronic eng.	0.1 - 8.9	3.9	5			
Farming, mining, constr.	0.02 - 9.6	5.0	5			
Communications, transport	1.3 - 18.6	7.1	3			
Clerical, offices	0.8 - 17.3	7.9	5	2.8 - 94.0	37.4	7
Shopkeepers, sales, serv.	0.03 - 50.8	16.1	5	3.4 - 48.4	23.6	3
Retired	8.6 - 64.9	37.7	6	48.1 - 92.3	70.2	2

L1 L2 etc represent the equivalent continuous A-weighted sound pressure levels for each activity where a domestic appliance is used.

Table 9.2 presents the results for male and female students.

When these levels are compared with an 8 hour daily noise exposure of 90 dBA (the occupational noise exposure as laid down in the Code of Practice for Reducing the Exposure of Employed Persons to Noise, 1972. [123]), it can be seen that the levels experienced by students using domestic appliances are very small, and therefore domestic appliance noise can not be regarded as a hazard to hearing.

This work can be expanded to a more general population by using information about:

- noise levels emitted by domestic appliances in typical locations throughout the home
- how individuals use their time.

Table 9.2 8 hour daily personal noise exposures resulting from exposure to domestic appliance noise.

	Male			Female		
Occupation	Range	Average	No.	Range	Average	No.
Housewife				55 - 71	62.6	21
Armed Forces	53 - 63	59.7	4			
Admin./manager	53		1	57		1
Teachers	55 - 63	60.8	6	64 - 67	65.0	6
Medical, social	56 - 72	64.0	3	50 - 68	60.4	7
Qualified scientist and eng.	58 - 64	62.5	7	53 - 69	62.7	8
Technical personnel	50 - 61	56.2	5	61 - 70	66.5	8
Electrical, electronic eng.	50 - 61	56.2	5			
Farming, mining, constr.	56 - 62	59.0	5			
Communications, transport	54 - 59	56.5	3			
Clerical, offices	48 - 61	54.2	5	43 - 65	55.5	7
Shopkeepers, sales, serv.	59 - 69	63.5	5	55 - 63	58.3	3
Retired	54 - 69	62.2	6	63 - 64	63.5	2

9.2.2 Measurement of domestic appliance noise levels

In another optional assignment Open University students of the T234 course are required to measure A-weighted sound pressure level (L_{pA}) of an appliance in their home, at various distances around the appliance (where possible). Table 9.3 presents the levels recorded for different appliances (418 measurements in total, standardised to the level 1 m from the appliance).

9.2.3 Time Budget Data

Information relating to how individuals use their time was extracted from a survey, conducted between January and March 1973, by the University of Cambridge [124], which aimed to investigate patterns of day-to-day activities of individuals in Reading, and involved a personal interview covering yesterday's activities and the completion of a six day diary.

Activities were classified into broad classifications, which consisted of numerous sub-divisions. Several sub-divisions have been selected that involve

Table 9.3 Range of A-weighted sound pressure levels of domestic appliances (L_{pA}) - 1m from the appliance.

Appliance	Range L_{pA}	Average L_{pA}	Number
Vacuum Cleaner	49 - 93	73.5	250
Hair Dryer	45 - 83	66.3	93
Washing Machine	60 - 82	70.9	17
Food Mixer	60 - 88	74.6	46
Shaver	65 - 69	67.0	2
Refrigerator	36 - 57	44.9	7
Spin Dryer	51 - 59	56.3	3

the use of domestic appliances. These are presented in Table 9.4.

Table 9.4 Comparison of equivalent continuous A-weighted sound pressure levels for selected activities - Reading and Open University data.

Activity	Duration (mins)	Appliance	L_{pA}	L_{Aeq}	L_{Aeq}(OU)
Housework/tidying (1)	127	Vacuum cleaner	73.5	67.0	64.5
Styling hair (2)	30	Hair dryer	66.3	64.5	67.1
Washing clothes(3)	45	Washing machine	70.9	69.1	64.4
Cooking/preparing food (4)	64	Food mixer	74.6	66.5	63.2

The estimations shown in Table 9.4 are based on the following assumptions:

1. During 127 minutes of housework, a vacuum cleaner is used for 30 minutes.

2. During 30 minutes of hair styling, a hair dryer is used for 20 minutes.

3. During 45 minutes of washing clothes, a washing machine is used for 30 minutes.

4. During 64 minutes of cooking and preparing food, a food mixer is used for 10 minutes.

Using A-weighted sound pressure level values in Table 9.3, equivalent continuous A-weighted sound pressure levels were calculated for the period of the activity (see column 5 of Table 9.4) using the following equation:

$$L_{Aeq}(activity) = L_{pA} + 10\,log\frac{Time\ spent\ using\ appliance}{total\ time\ of\ activity} \qquad (9.3)$$

where L_{pA} represents the value measured for the appliances (see Table 9.3) used in the activity.

The equivalent continuous A-weighted sound pressure levels calculated for the activity times of the Reading population are not too dissimilar to those measured by the Open University students (presented in column 6 of Table 9.4), which suggests the results could be extrapolated to a more general population.

However, before doing so, it is of interest to compare the two populations (O.U. students and Reading) in terms of how the people spend their time. This will directly affect conclusions drawn about the contribution of domestic appliance noise to 24 hour equivalent continuous A-weighted sound pressure level. For this analysis, the Open University data has been classified in a manner that resembles the classification of the Reading Survey [125]. The results are presented in Table 9.5.

From Table 9.5 the following observations can be made:

1. Open University students spend more time in private study than the general population thus reducing the time available to spend in other activities e.g. sleeping, organised leisure.

2. Female students worked longer hours therefore reducing the time available for: domestic activities, television, organised leisure.

3. The Reading Survey excluded retired respondents, but 8% of Open University students were retired. This may explain the increase in the amount of time spent in shopping, casual social, drinking(alcoholic) and miscellaneous activities.

4. More time is spent travelling (largely to and from work) which probably reflects present day trends to live farther away from the place of

Table 9.5 Comparison of the time spent (in minutes) in various activities by people who engaged in the activities.

	Male		Female	
Activity	Reading	O.U.	Reading	O.U.
Sleep	504	475	522	501
Work	443	445	176	389
Eating	91	139	84	140
Drinking (alcoholic)	35	85	19	-
Casual social	68	156	82	100
Organised leisure	40	-	48	-
Private leisure/study	80	148	78	165
Television	146	156	132	108
Personal hygiene	41	34	42	40
Domestic	60	80	228	157
Child care	26	63	59	113
Shopping	20	94	36	71
All travel	95	130	72	121
Miscellaneous	43	80	43	82

work and commute to work.

5. In terms of activities potentially involving domestic appliances - namely watching television, personal hygiene (hair dryer), and domestic (vacuum cleaner, washing machine, food mixer) there is a similarity between how the two populations spend their time.

It can be concluded that the Open University population is fairly typical of a more general population in terms of the time spent in various activities and in the likely noise exposure resulting from these activities.

9.3 Conclusions

In comparing the time spent in various activities, and also recorded equivalent continuous A-weighted sound pressure levels for those activities with a more general population, it can be concluded that the Open University population showed good agreement with the general population, and it can be concluded that:

1. The percentage contribution of domestic appliance noise to a typical 24 hour noise dose varies widely, between 0.02 and 99. Over 50% of the total energy dose for 47% of housewives, 83% of female teachers, 33% of male teachers and 37.5% of retired people was contributed by domestic appliance noise. 20% of female students and 3% of male students received more than 75% of their total energy (corresponding to 24 hour noise exposure) from domestic appliances. At the other extreme, for 36.5% of female students and 79% of male students, the contribution by domestic appliance noise was less than 25%.

2. The people most affected by domestic appliance noise were housewives, teachers and those who were no longer working.

3. The percentage of the corresponding total energy contributed by domestic appliance noise is systematically greater for females (42% of total energy, on average) than for males (22% of total energy, on average).

4. Domestic appliance noise is insignificant when compared with a daily personal noise exposure level ($L_{EP,d}$) of 90 dBA, the level recommended for occupational noise exposure.

Chapter 10

Conclusions and Suggestions for Further Work

10.1 Conclusions

10.1.1 The objective components of the noise that influence a particular subjective reaction

1. Appliance type appeared to influence the noisiness ratings given to each appliance such that the noise of hair dryers and vacuum cleaners were generally rated lower than those of kitchen appliances, even though their sound power levels were the same. The strength of this relationship was seen to be dependent on the noise index with which ratings were correlated. The relationship was strongest when noisiness ratings were correlated with A-weighted sound power levels. Therefore labelling appliances with their A-weighted sound power level will not sufficiently account for subjective reactions to the noise of different appliance types. A separate labelling system for each family of appliances would be more useful. When equivalent continuous A-weighted sound pressure level was correlated with noisiness ratings, the strength of the relationship diminished.

2. Noisiness ratings were seen to increase when the duration of exposure to appliance noise increased from 15 to 30 seconds. However in a repeat experiment, during which the exposure time decreased, there

was no significant difference between noisiness ratings for 30 and 15 seconds. Further work is required to investigate this relationship fully (see section 10.2).

3. Whether the subject was using the appliance or listening to it determined their noisiness ratings. Subjects rated the four appliances investigated as follows:

    - the vacuum cleaner was rated noisier when subjects were listening to it being used by another subject. However, this was attributed to a discrete frequency at 250 Hz that occurred in the listener position.
    - the food processor was rated noisier when subjects were using it, which was attributed to the sound pressure level being higher in the user position.
    - there was no significant difference between user/listener ratings for the hair dryer and liquidiser.

    Further work is required to investigate the extent of this relationship (see section 10.2).

10.1.2 The success of A-weighted sound power level index and other noise indices in correlating with subjective ratings to appliance noise

There were two aspects to this investigation:

- determining which subjective reaction is the most consistent when correlated with the noise indices under investigation.
- determining which noise index shows that highest correlation with subjective reactions.

Which subjective reaction is the most consistent when correlated with the noise indices under investigation?

The subjective reactions examined were: annoyance, noisiness and acceptability (usefulness is not included here as it was not a subjective reaction to the noise). Although each rating scale gave significant correlations with all noise indices at $p=.05$ level of significance (at least), when regression analysis was carried out and the results examined, it was found that more of the variance observed was explained by the regression equation for noisiness ratings. Thus it was concluded that the noisiness rating scale was the most consistent of the subjective ratings examined in the study.

Which noise index correlated the best with noisiness ratings?

All the noise indices gave correlations at $p=.001$ level of significance. However, after using a statistical technique known as 'bootstrapping' it was concluded that for this series of experiments, and for the appliances investigated, maximum A-weighted sound pressure level, equivalent continuous A-weighted sound pressure level and single event noise exposure level indices correlated the most successfully with noisiness ratings. Correcting for tonal components did not improve the correlations. A-weighted sound power level performed the least successfully of all the indices.

10.1.3 The contribution of domestic appliance noise to the total daily noise dose of an individual

The contribution of domestic appliance noise to the total daily noise dose of an individual was found to vary considerably, depending on the sex of the individual and their occupation. However, when converted to a daily personal noise exposure of 8 hours ($L_{EP,d}$), the levels experienced are very small (when compared with $L_{EP,d}$ of 90 dBA, the recommended occupational noise exposure).

10.2 Further Work

1. Further investigation into the effect of appliance family type on noisiness ratings is required. Although a relationship was established whereby hair dryers and vacuum cleaners were rated less noisy than kitchen appliances of similar A-weighted sound power levels, insufficient numbers of the other appliances prevented examination of this relationship further.

2. From the results of the experiments described in this thesis, it would appear that the EEC have chosen the wrong noise index for labelling airborne noise of household appliances. It has been demonstrated that in terms of a correlation with subjective reactions other noise indices were superior to A-weighted sound power level. The feasibility of a label containing both A-weighted sound power level and equivalent continuous A-weighted sound pressure level, as measured in a standardised test environment, must be considered.

3. The implications of using an equivalent continuous A-weighted sound pressure level label on appliances of cyclical nature (e.g. washing machines, dishwashers) needs to be assessed in an attempt to determine whether a single value label will be sufficient, or whether a selection of values corresponding to each part of the cycle are more appropriate for the consumer.

4. The effect of directionality of the appliance on noisiness ratings for users and listeners, is considered worthy of further investigation. It may be possible that the noise directional characteristics of an appliance affect the subjective ratings of the noise level in user and listener positions. As was identified in this study, the vacuum cleaner (used in the experiment to investigate Hypothesis 3) emitted a discrete frequency component at 250 Hz at the listener position and it was suggested that this caused the noisiness ratings to be significantly higher in the listener positions.

If this phenomenon is found to occur for other appliances, then it may be more useful for the consumer to be presented with a specification of the appliance's noisiest directions.

5. Further work is required to investigate the effect on subjective ratings caused by varying the exposure time to appliance noise. Although a relationship was determined between elongation of exposure and noisiness ratings, the experiment to determine the effect of a decrease in exposure time on ratings was inconclusive. It is recommended that in future work the experimenter intermingle the exposure times by having long and short exposures in the same session, and not classifying them into separate sessions as in this study. It is also recommended that annoyance reactions be investigated as an annoyance reaction could also be dependent on the duration of the exposure.

   The results of such a study could have important implications for the labelling of domestic appliances. If it is confirmed that appliances used for short duration are rated as less noisy than appliances used for longer duration, then consumers will find the proposed efficiency component of a domestic appliance label very useful. For example, when choosing between two food mixers, the consumer would be wise to purchase the one that is most efficient, as it will perform its task in a shorter duration than one of lesser efficiency, and thus will be rated as less noisy.

6. From the experiences of this research, it is recommended that future experiments have the following design features:

   - In experiments where two sessions are part of the experimental procedure, it is recommended that experimenters allow sufficient time to pass between successive sessions e.g. 15 minutes (at least). This will help to dissipate the effect on subjects of earlier presentations and thus help to eliminate the carry-over effect.
   - A wider range of appliances should be included in future studies. More specifically, equal numbers of each appliance type would

help overcome many of the problems experienced.

- If possible, all the appliances should be presented in one experimental session to avoid the grouping problems and confounding of the scale experienced in these experiments. The balanced Latin square design is considered a satisfactory method for ordering the presentation of appliances.

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Glossary of acoustical and psycho-acoustical terms

Absorption coefficient (α): If a surface is exposed to a sound field, 'α' is the ratio of the sound energy absorbed by the surface to the total sound energy which strikes it; if it absorbs 60 % of the incident energy the absorption coefficient is 0.6.

Anechoic: Almost totally sound-absorbent at a very wide range of frequencies. An anechoic chamber gives almost free field conditions.

Annoyance: The feeling of displeasure associated with any agent or condition believed by an individual or group to be adversely affecting them.

Audiogram: A graph, usually automatically plotted by an audiometer, showing a subject's hearing response or loss as a function of frequency. A separate graph is usually given for each ear.

Audiometry: The measurement of hearing.

Category scaling: Scaling subject's responses along a verbal or numerical rising scale.

Carryover effects: The effects on a subject's performance under one condition of previously administered conditions in a within-subjects design.

Community Noise Equivalent Level (CNEL): An index which describes the noise of aircraft flyovers, or community noise generally, over 24 hours.

Day-night sound level (L_{pDN}): A statistical descriptor of the sound over a 24 hour period taking account of the fact that sounds are more annoying at night than during the day. Calculated by determining the equivalent sound level over a period of 24 hours after adding 10 dBA to the sound levels occurring in the period 10 pm to 7 am.

Decibel (dB) (one-tenth of a Bel): A means of denoting the ratio of two quantities when the range of values is very great. A Bel can be described as the number of tenfold increases the lower quantity must be given to the higher, i.e. $\log_{10}\frac{i_1}{i_2}$; to obtain the answer in decibels, multiply by 10.

Equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$): The value of the A-weighted sound pressure level of a continuous sound that, within a specified time interval,T, has the same mean square sound pressure as a sound under consideration whos level varies with time.

Free field: A sound field in a medium of such extent that the effects of the boundaries are negligible throughout the region of interest. A free-field anechoic room is one designed to simulate free-field conditions.

Frequency: The number of times a vibrating system or particle completes a repetitive cycle of movement in a period of one second, expressed in Hertz or 'cycles per second'.

Hertz: Unit of frequency.

Index: Combines level with frequency, tone correction, variation in time or frequency of occurrence e.g. dBA, dBB, dBC, dBD, PNL, L_{Aeq}, L_{AX} etc.

L_{Amax}: Maximum A weighted sound pressure level occurring during an event, for a period of 3 seconds.

Level: The expression of a unit in logarithmic terms with respect to a reference value e.g. 20μ Pa, 10^{-12} watts.

L_{pn}: The sound pressure level exceeded n% of the time over a given period. Thus L_{p1}, L_{p10}, L_{p50}, L_{p90}.

Loudness: A judgement of the strength of a sound by a human being. It is dependent on sound pressure and frequency. Over much of the range, a threefold increase in sound pressure is considered a doubling of loudness. This change is just under 10 dB.

Magnitude Estimation: A method involving the pairing together of a number of stimuli and asking subjects to relate their perception of the second stimulus based on their perception of the first.

Noise: Sound unwanted by the listener, meaningless sound.

Noisiness: The degrees of unwantedness of a not unexpected, non-pain or fear-producing sound as part of ones environment.

Noy: A unit of noisiness related to perceived noise level in PNdB.

One-third octave: A band of frequencies the highest frequency of which is $(2)^{\frac{1}{3}}$ or $10^{0.1}$ greater than the lowest. There are three such bands in an octave band.

Perceived noise level (PNdB): The sound pressure level of between one third of an octave and an octave of random noise at 1000 Hz, which is considered by 'normal' people to be equally noisy to the sound of interest.

Psychoacoustics: The science of investigating acoustical matters from the standpoint of psychology.

Pure tone: A sound of a single (i.e. discrete) frequency. Perceived as a 'pure' note e.g. whine, buzz, ring, squeal.

Ratings: Bring into account the specific time of day and perhaps seasons in the human assessment of noise e.g. L_{pDN}, CNEL.

Reverberant field: A sound field resulting from the superposition of many waves due to repeated reflections at the boundaries.

Reverberation: Sound in a room which builds up owing to multiple reflections from surrounding surfaces. It will persist after the source has stopped emitting sound.

Reverberation room: A room designed to facilitate the production of approximately diffuse sound fields.

Reverberation time: The time it takes for reverberant sound of a given frequency to decay by 60 dB after the source is cut off. It is usual to measure the first 30 dB of decay and extrapolate the rest.

Single event noise exposure (L_{AX}): The continuous sound level which, when maintained for one second, contains the same quantity of sound energy as the actual time varying level of a noise event. It is a logarithmic measure of total energy.

Sound: Wave motion in an elastic medium, or the sensation of hearing this may produce.

Sound exposure: The cumulative acoustic stimulation at the ear of a person over a period of time. Also known as Noise Dose when the exposure of one individual is described.

Sound power level (L_W): The total energy per second emitted by the source as sound expressed in decibels, re 10^{-12} watts.

Sound pressure level (L_p): The effective sound pressure, or root-mean square values of the pressure fluctuations above and below atmospheric pressure caused by the passage of a sound wave, expressed in decibels re 2 x 10^{-5} N/m^2.

Spectrum: A group of continuous frequencies rising from low to high.

Tone correction: A number to be added to a scale of noisiness (usually PNL) to account for the presence of pure tones.

Unit: Refers to the unit of measurement e.g. Pascal, unit of sound pressure; or Watt, unit of sound power.

Weighted sound pressure level: A level of sound pressure in which the sound pressure levels of the various frequency bands have been weighted according to a number of weighting scales e.g. L_{pA},L_{pB}, L_{pC}, $and L_{pD}$.

Glossary of Statistical Terms

Analysis of variance: A statistical technique involving the comparison of variances reflecting different sources of variability.

Arithmetic mean: The sum of a set of numbers divided by the number of them in the set.

Block randomization: A method of random assignment in which subjects are balanced over the conditions at the end of each subject assignment block.

Bootstrapping: A statistical technique which allows one to generate the sampling distribution of the test statistic, and thus calculate the p value for that test statistic.

Categorical data: Data consisting of a classification of the behaviour of subjects into a number of mutually exclusive response categories.

Central Limit Theorem: A theorem of statistical theory stating that the sampling distribution of the mean approaches the normal distribution in shape as the size of the random sample on which the means are based is increased.

Confidence level: Used in interval estimation to refer to the proportion of times confidence intervals constructed in the same way will include the population parameter.

Correlation coefficient: A measure of the degree of linear relationship between two variables.

Degrees of freedom ***(df)*****:** The number of independent pieces of information remaining following the estimation of population parameters.

Experiment: A set of procedures permitting the inference of cause and effect. Differential treatments are administered randomly to different groups of subjects (or the same subjects in a counterbalanced manner) and performance on some response measure is observed and recorded following the administration of the treatments. Any differences observed among the treatment conditions that are not reasonably accounted for by experimental error are attributed to the critical differences in the treatments associated with the different conditions.

Experimental design: The plan of an experiment, including a specification of the nature of the treatment conditions and the method of assigning subjects to the conditions.

Experimental error: Uncontrolled sources of variability that are assumed to occur randomly during the course of an experiment.

F ratio: A statistical index relating systematic variance to nonsystematic variance. The statistical procedure permitting an assessment of the significance of this ratio is called the F test.

Homogeneity of Variance: An assumption of the analysis of variance referring to the equality of the treatment population variances.

Latin Square: A form of counterbalancing used in the arrangement of orders in which treatment conditions are presented in a within-subjects design.

Linear regression line: A best-fit straight line depicting the linear relationship between two variables.

Linear regression of X on Y: The linear regression line relating values on the X variable to values on the Y variable. Can be used to predict X from a knowledge of Y.

Main effect: The overall effect of one independent variable in a factorial design averaged over the levels of the second independent variable.

Mean: A measure of central tendency; the arithmetic average. The sum of a set of numbers divided by the number of them in the set.

Mean square: A term for the variances calculated in the analysis of variance. A sum of squares is divided by the appropriate number of degrees of freedom.

Median: A measure of central tendency; the score above or below which half the scores lie.

Non-parametric test: A collection of statistical tests used for investigating the effects of single variables and when the experimental data do not meet the three assumptions of parametric tests (see **Parametric tests**). (Tests include Spearman's Rank Correlation Coefficient, Sign Test).

Normal distribution: A theoretical distribution commonly observed in nature, especially when the characteristic being measured is influenced by a large number of independent factors.

Parametric tests: A collection of statistical tests used to analyse the interactions between two or more variables when: the experimental scores are measured on at least an interval scale; when the scores are normally distributed; and when there is **Homogeneity of Variance** between scores in the experimental condition. (Tests include **Analysis of Variance, t-test**).

Post-hoc comparison: A comparison conducted after the data have been examined.

Product-moment correlation coefficient (r): The most common index of the linear relationship between two variables. ranges from -1.0 to + 1.0 (perfect negative and perfect positive correlations, respectively); a value of 0 represents the complete absence of correlation.

Proportion of variation due to linear regression: The proportion of variance in either variable X or variable Y that is linearly associated with the other variable. Measured by the square of the product-moment correlation coefficient.

Randomization: Procedures used to randomize the assignment of subjects to the treatment conditions of an experiment.

Random sample: A sample drawn randomly from a population.

Research hypothesis: A hypothesis based on empirical and theoretical considerations that leads to the design of an experiment.

Residual sums of squares: In within-subjects designs, a sums of squares reflecting experimental error. With correlational data, a sums of squares reflecting the variation not accounted for by the linear relationship between two variables.

Residual variation: Variability reflecting the deviation of observed data points from the linear regression line linking two variables.

Sample: A subgroup drawn from a population or larger group of subjects.

Sample size: The number of subjects assigned to a particular treatment condition or observed in a sample.

Sampling distribution: A frequency distribution of a statistic obtained from an extremely large number of random samples drawn from a specified population.

Significance level: The probability with which the experimenter is willing to reject the null hypothesis when in fact it is correct.

Standard deviation: A measure of variability; the square root of the variance. Expresses variability in terms of the original units of measure.

Standard error of estimate: The square root of the variance based on the deviation of the observed scores on the predicted variable from those predicted from the linear regression line.

Standard error of the mean: The standard deviation of the sampling distribution of the mean.

Statistical significance: A finding that is established through the rejection of the null hypothesis.

***t*-test:** A statistical test that uses the t distribution to assess the adequacy of the null hypothesis. Algebraically equivalent to the F test when applied to the analysis of experiments.

Type I error: An error of statistical inference that occurs when the null hypothesis is true but is rejected. An error of 'seeing too much in the data'.

Type II error: An error of statistical inference that occurs when the null hypothesis is false, but is not rejected. An error of 'not seeing enough in the data'.

Variability: Differences among scores in a distribution. Most commonly expressed as a variance or a standard deviation (the square root of the variance).

Variance: A measure of variability; an average of the sum of the squared deviations from the mean.

Appendix A

Measurement of the Reverberation time of the Chamber

These measurements were necessary to determine the minimum distance between the sound source and the nearest microphone position. The reverberation time (being defined as the time taken for a sound, instantly switched off, to drop in level by 60 dB [39]) was determined over three microphone positions and for three frequencies - 100 Hz, 1000 Hz and 3150 Hz. The following equipment was used:

1. Sound Generating Equipment

   Sine random generator - Bruel and Kjaer Type 1027

   Power amplifier - H H Electronic Type 25.D

   Loud speaker - 12 inch loud speaker constructed by Building Research Establishment

2. Measuring Equipment

   Three half inch microphone capsules - Bruel and Kjaer Type 4165

   Three microphone preamplifiers - Bruel and Kjaer Type 2619

   Band pass filter set - Bruel and Kjaer Type 1615

   Chart level recorder - Bruel and Kjaer Type 2307

A sine random generator was programmed to emit white noise. For each frequency band of interest, the following procedure was followed:

1. The level recorder and generator were switched on and traces were made on the level recorder output of the signal detected by the microphone.
2. The generator was switched off and the decay of sound in the chamber was recorded as a trace on the level recorder print-out.

When the sound had decayed completely, the reverberation time was calculated using Bruel and Kjaer level recorder protractor Type SC2361, whereby the slope of the recorded decay curve is determined and thus the reverberation time is calculated. Using the band pass filter set, the frequencies of interest could be investigated and the procedure, as described, was followed for each microphone positions and for each frequency of interest. The results are presented in Table A.1.

Table A.1 Reverberation times for the reverberation room.

Microphone	100 Hz	1000 Hz	3150 Hz
Microphone 1	17.0	13.60	5.40
Microphone 2	22.0	12.60	5.60
Microphone 3	20.0	12.40	5.40
Average RT	19.6	12.86	5.46

Appendix B

A-weighted sound power levels of domestic appliances

This appendix presents the A-weighted sound power levels of the domestic appliances investigated during the investigation. The are presented in a series of tables showing the A-weighted sound power level for each one-third octave centre frequency.

B.1 Hair Dryers

Table B.1 One-third octave A-weighted sound power levels for Hair Dryers I - VI

One-third octave centre freq (Hz)	HD I	HD II	HD III	HD IV	HD V	HD VI
100	21.3	15.3	19.9	20.6	24.5	17.5
125	25.6	17.3	22.8	20.2	27.0	18.9
160	32.0	26.3	27.5	25.8	30.5	25.5
200	39.7	35.7	32.7	35.7	34.3	37.3
250	41.8	31.3	51.4	41.9	40.0	34.1
315	44.5	38.2	44.1	39.3	46.0	40.1
400	49.0	43.9	45.7	46.1	47.8	49.0
500	56.9	43.7	54.3	52.5	56.5	50.7
630	67.9	48.1	53.8	60.6	67.0	52.8
800	73.7	52.5	58.7	58.1	64.9	63.5
1000	75.0	53.4	63.5	52.2	57.1	62.1
1250	66.3	55.8	63.6	55.3	60.6	64.9
1600	70.4	56.4	63.0	60.9	67.0	64.3
2000	67.5	57.4	62.5	63.7	65.0	64.4
2500	64.7	58.4	62.6	57.5	69.4	63.1
3150	67.4	60.0	65.4	59.2	68.5	64.9
4000	65.5	64.2	66.8	60.8	67.8	63.8
5000	65.1	57.8	72.8	60.9	69.9	63.6
6300	65.0	60.1	67.1	61.5	69.3	63.9
8000	63.6	58.7	66.0	61.1	70.4	61.6
10000	58.4	57.6	67.1	59.3	67.5	58.7

HD I = Clairol 1200 - Speed 1

HD II = Boots MD2 - Speed 1

HD III = Boots MD2 - Speed 2

HD IV = Moulinex 722 - Speed 1

HD V = Moulinex 722 - Speed 2

HD VI = Braun Compact 1500 - Speed 1

Table B.2 One-third octave A-weighted sound power levels for Hair Dryers VII - XI

One-third octave centre freq (Hz)	HD VII	HD VIII	HD IX	HD X	HD X1
100	21.5	17.6	29.8	18.3	25.4
125	23.6	18.0	24.1	22.3	27.5
160	29.0	24.7	28.7	28.4	32.3
200	34.1	29.3	33.5	34.6	37.2
250	47.7	42.1	38.8	37.0	50.6
315	45.6	39.1	49.4	43.0	54.7
400	51.1	44.0	48.7	50.1	53.4
500	59.3	49.4	54.1	56.3	61.9
630	56.9	56.8	60.1	62.5	67.5
800	63.2	63.9	67.0	64.0	67.9
1000	62.1	68.6	69.7	62.9	65.7
1250	66.6	67.7	69.8	63.0	75.3
1600	74.5	66.1	71.6	62.3	73.3
2000	68.9	67.6	74.3	62.3	69.7
2500	69.0	64.7	70.6	61.1	68.8
3150	72.8	63.4	71.5	63.6	69.2
4000	72.6	62.6	69.2	61.4	74.3
5000	71.7	61.9	69.1	60.9	69.6
6300	71.0	62.1	68.6	61.5	71.1
8000	68.5	63.2	68.6	62.0	69.1
10000	65.7	61.8	67.8	59.0	67.2

HD VII = Braun Compact 1500 - Speed 3

HD VIII = Braun Supercompact 1200 - Speed 1

HD IX = Braun Supercompact 1200 - Speed 2

HD X = Ronson Hotshot - Speed 1

HD XI = Ronson Hotshot - Speed 2

B.2 Vacuum Cleaners

Table B.3 One-third octave A-weighted sound power levels for Vacuum Cleaners I - IV

One-third octave centre freq (Hz)	VC I	VC II	VC III	VC IV
100	42.8	46.7	52.3	48.7
125	39.4	45.3	42.9	42.0
160	50.5	52.1	51.5	48.5
200	46.3	61.2	57.6	52.7
250	53.7	68.3	84.9	58.1
315	61.7	78.4	87.7	65.2
400	59.4	71.5	73.5	63.6
500	67.5	72.8	82.0	65.9
630	66.4	79.9	84.4	67.6
800	64.9	78.4	82.0	68.5
1000	64.9	76.8	83.2	69.6
1250	64.5	77.2	85.0	72.7
1600	69.3	79.5	82.7	73.2
2000	71.3	78.5	81.0	70.7
2500	64.4	79.8	83.7	68.6
3150	61.7	74.4	79.2	67.4
4000	57.2	70.2	75.8	65.7
5000	59.0	71.0	72.9	64.3
6300	56.3	69.1	69.7	61.1
8000	56.9	66.7	66.1	60.1
10000	52.1	63.8	62.2	59.0

VC I = Electrolux 520S

VC II = Hoover U2002

VC III = Hoover 119

VC IV = Kerstar C606 Supreme

Table B.4 One-third octave A-weighted sound power levels for Vacuum Cleaners V - VIII

One-third octave centre freq (Hz)	VC V	VC VI	VC VII	VC VIII
100	45.3	47.6	49.5	49.2
125	43.5	53.5	53.7	52.6
160	49.5	57.1	57.1	55.9
200	55.8	55.8	59.7	59.0
250	63.3	62.0	61.7	60.7
315	72.9	72.2	79.1	71.9
400	62.1	65.0	70.2	65.7
500	66.1	69.2	69.8	68.2
630	69.4	70.7	72.8	71.0
800	69.4	69.4	72.5	70.8
1000	67.2	69.9	70.9	68.4
1250	70.9	67.4	70.7	68.5
1600	73.5	66.2	67.5	65.4
2000	67.1	69.9	67.1	64.8
2500	67.5	66.4	65.1	62.9
3150	66.5	62.2	65.6	63.5
4000	64.3	61.3	65.0	62.8
5000	59.4	59.6	65.7	63.4
6300	56.4	55.9	64.4	61.9
8000	55.1	54.8	62.4	60.0
10000	52.4	54.7	61.4	58.9

VC V = Electrolux 345

VC VI = Electrolux ZA65

VC VII = Electrolux 350E - Superboost

VC VIII = Electrolux 350E

B.3 Food Mixers

Table B.5 One-third octave A-weighted sound power levels for Food Mixers I - IV

One-third octave centre freq (Hz)	FM I	FM II	FM III	FM IV
100	38.4	42.8	36.5	40.8
125	40.7	48.0	31.1	54.2
160	39.9	47.7	32.3	58.7
200	54.2	55.2	42.2	52.1
250	49.4	56.3	48.5	56.3
315	46.3	54.9	59.9	59.0
400	50.9	58.8	58.2	68.1
500	51.8	61.2	65.2	68.5
630	55.0	66.8	63.8	70.7
800	58.1	63.2	60.8	69.3
1000	60.8	64.6	61.1	69.3
1250	61.5	67.9	63.9	72.9
1600	59.9	67.6	64.4	81.0
2000	59.4	66.4	64.7	74.1
2500	58.9	64.2	65.3	68.2
3150	57.9	64.1	62.3	68.6
4000	56.2	61.7	59.9	63.7
5000	54.6	59.4	61.1	62.2
6300	51.5	58.1	58.8	60.0
8000	49.9	56.5	57.9	58.4
10000	49.3	55.4	54.7	56.5

FM I = Philips HR1907 Speed - 1

FM II = Philips HM3060 - Speed 1

FM III = Kenwood Mini A345 - Speed 2

FM IV = Kenwood Chef A901 - Speed 4

B.4 Liquidisers

Table B.6 One-third octave A-weighted sound power levels for Liquidisers I - IV

One-third octave centre freq (Hz)	LIQ I	LIQ II	LIQ III	LIQ IV
100	37.2	55.0	44.2	46.2
125	57.1	50.3	38.3	47.6
160	59.1	51.7	42.6	49.9
200	56.1	60.0	49.8	59.1
250	60.0	54.5	68.2	66.9
315	64.0	59.9	55.9	58.6
400	70.9	66.1	64.2	67.1
500	70.8	65.0	72.0	75.4
630	72.1	64.9	63.5	74.3
800	70.7	66.1	66.5	71.0
1000	73.2	66.6	69.6	73.2
1250	76.7	66.4	72.0	74.7
1600	79.6	66.4	77.5	76.2
2000	76.5	66.3	72.7	73.7
2500	73.3	66.3	68.6	75.4
3150	73.2	63.2	70.6	70.9
4000	71.5	63.1	69.9	69.3
5000	68.9	60.6	69.6	72.9
6300	64.3	61.1	71.2	69.9
8000	61.9	60.0	69.0	67.3
10000	59.9	58.1	65.9	64.7

LIQ I = Kenwood Chef A901 and Liquidiser Attachment

LIQ II = Philips TX2000

LIQ III = Moulinex 530

LIQ IV = Moulinex 241.1

B.5 Food Processors

Table B.7 One-third octave A-weighted sound power levels for Food Processors I - III

One-third octave centre freq (Hz)	FP I	FP II	FP III
100	48.6	40.3	44.8
125	46.6	42.8	57.0
160	48.2	46.2	44.5
200	50.5	52.3	48.2
250	52.8	59.3	50.4
315	65.9	54.7	52.3
400	68.6	57.6	55.9
500	65.3	61.9	59.2
630	68.9	69.9	62.3
800	69.4	70.4	63.1
1000	68.9	72.6	67.1
1250	69.1	75.0	77.0
1600	72.4	75.0	74.3
2000	73.8	74.9	60.7
2500	73.5	79.8	66.7
3150	77.2	77.8	64.9
4000	85.1	76.8	60.1
5000	72.8	74.4	66.9
6300	70.4	69.5	66.7
8000	72.9	66.2	68.1
10000	69.4	65.4	63.8

FP I = Braun MC - 1

FP II = Robot Chef - RC3

FP III = Prestige L2001

Appendix C

Directional characteristics of a selection of domestic appliances

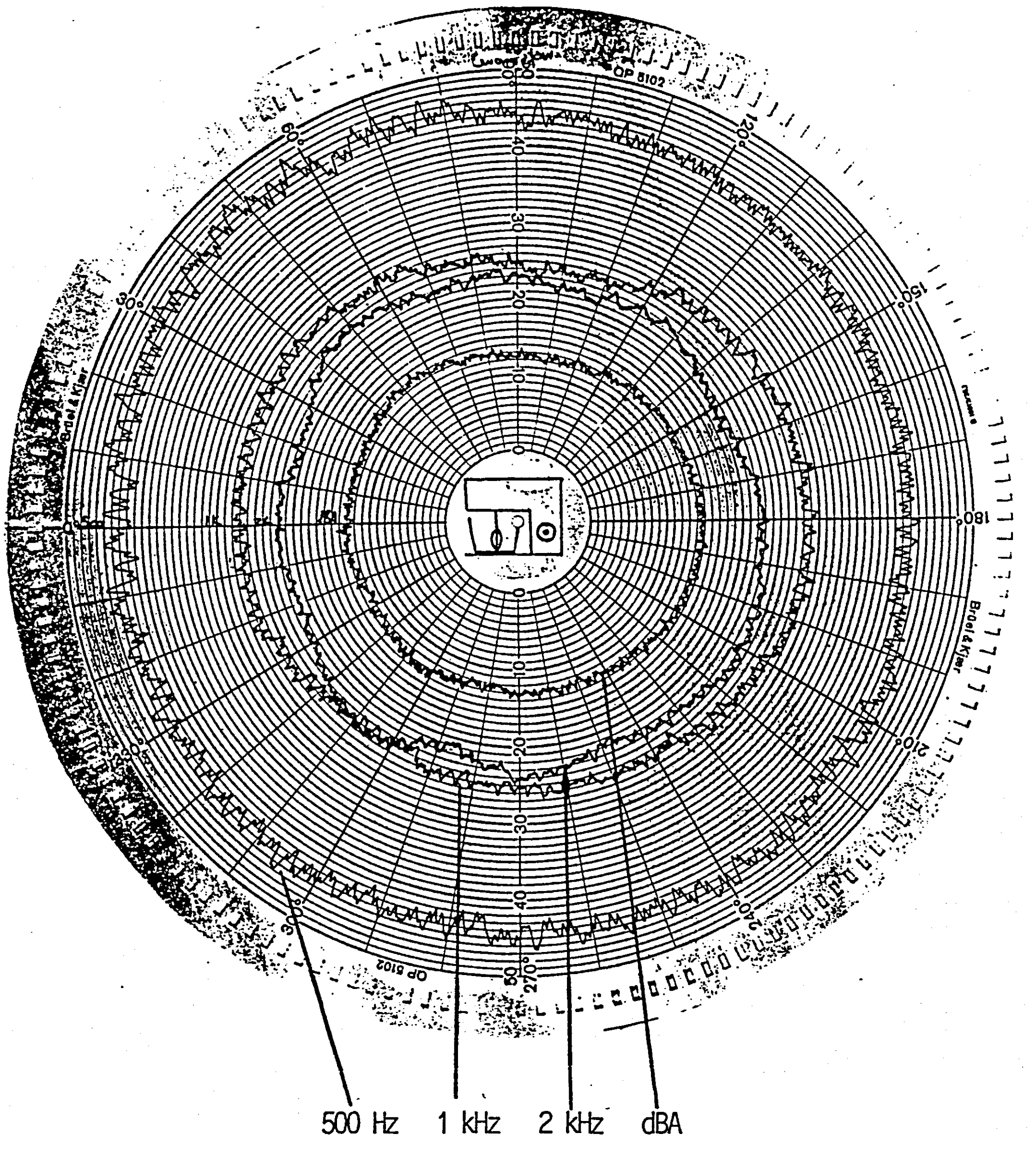
The directional characteristics of a selection of the domestic appliances used in this study are presented in this appendix, in the form of a polar plot, (as measured in an anechoic chamber at Building Research Establishment). Each plot consists of 4 different lines representing directionality measurements for

- 500Hz
- 1000Hz
- 2000Hz
- overall sound pressure level

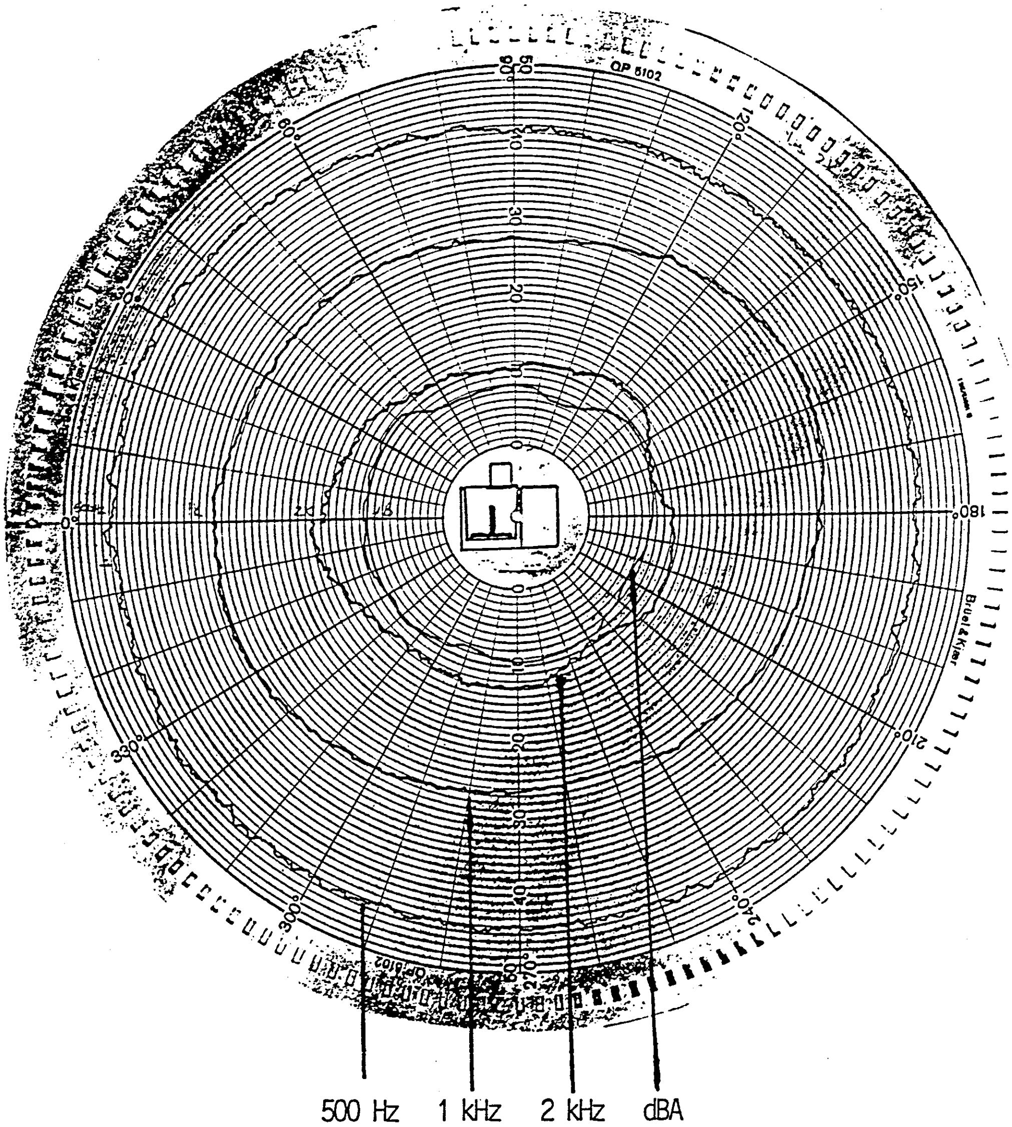
The directional characteristics of nine appliances were investigated:

- Kenwood Chef A901 Food Mixer - Speed 4
- Prestige L2001 Food Processor
- Philips HM3060 Food Mixer
- Philips TX2000 Liquidiser
- Hoover U2002 (upright) Vacuum Cleaner
- Electrolux ZA65 (cylinder) Vacuum Cleaner
- Braun Supercompact 1200 Hair Dryer - Speed 1
- Boots MD2 Hair Dryer - Speed 2
- Clairol 1200 Hair Dryer - Speed 1

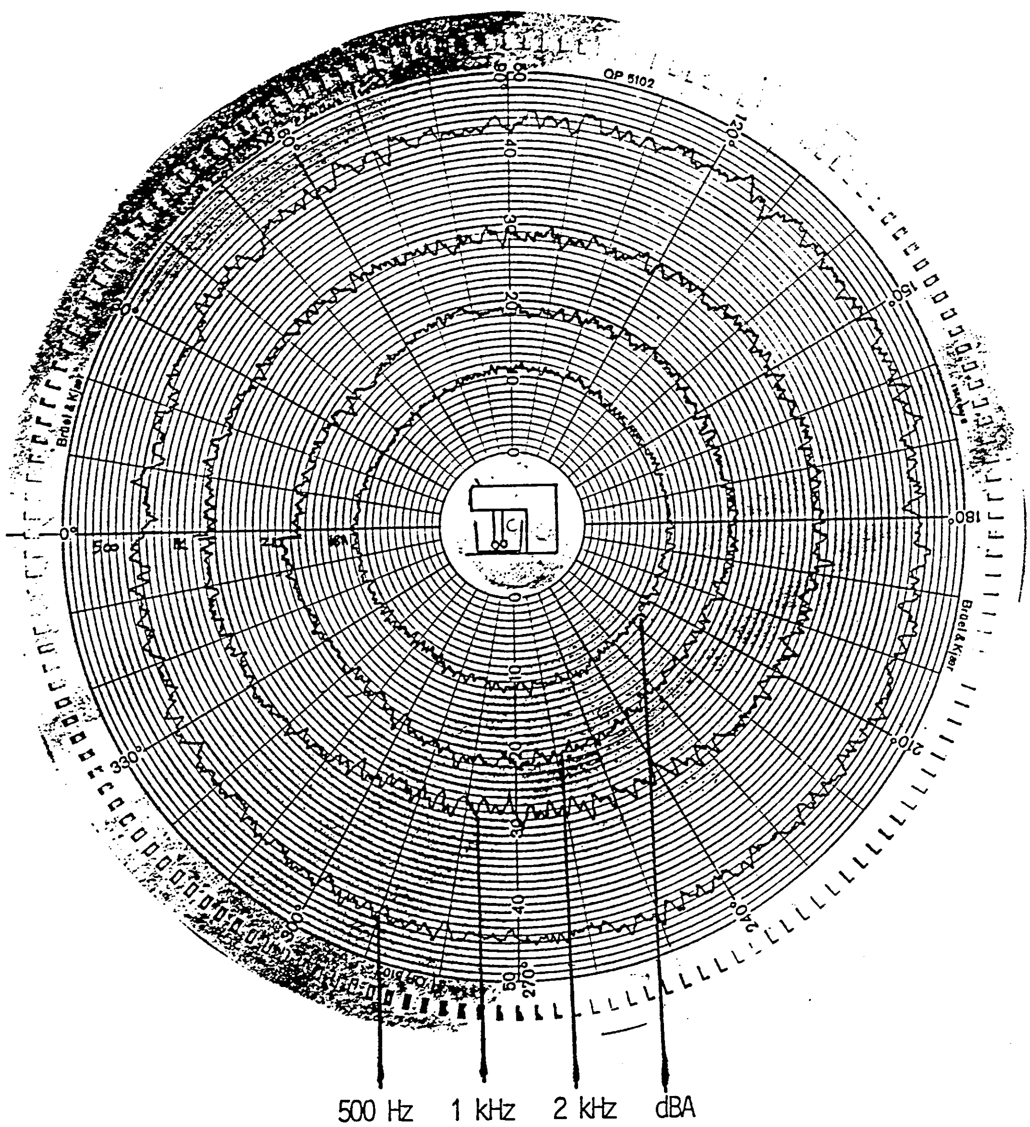
C.1 Kenwood Chef A901 Food Mixer - Speed 4



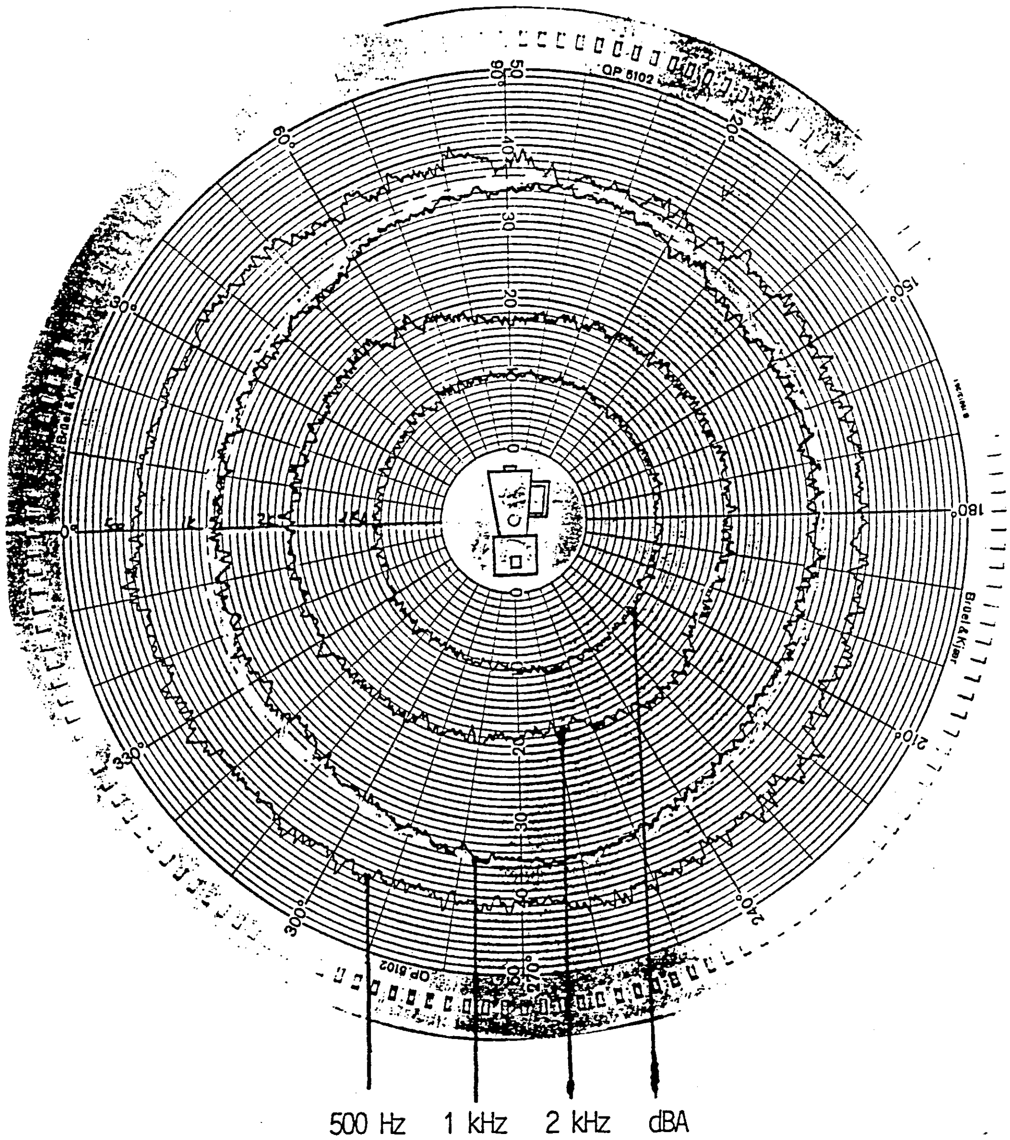
C.2 Prestige L2001 Food Processor



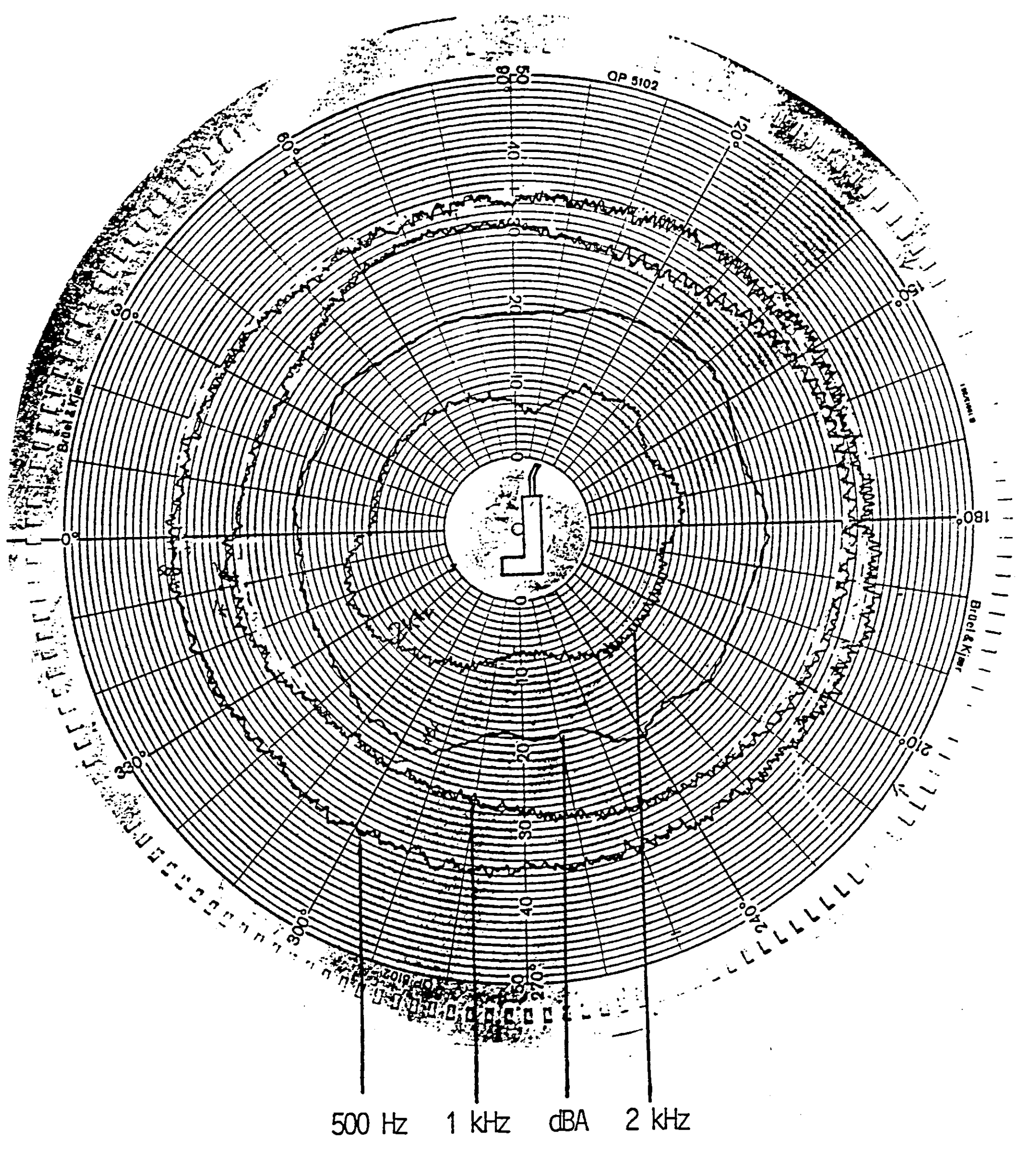
C.3 Philips HM3060 Food Mixer - Speed 2



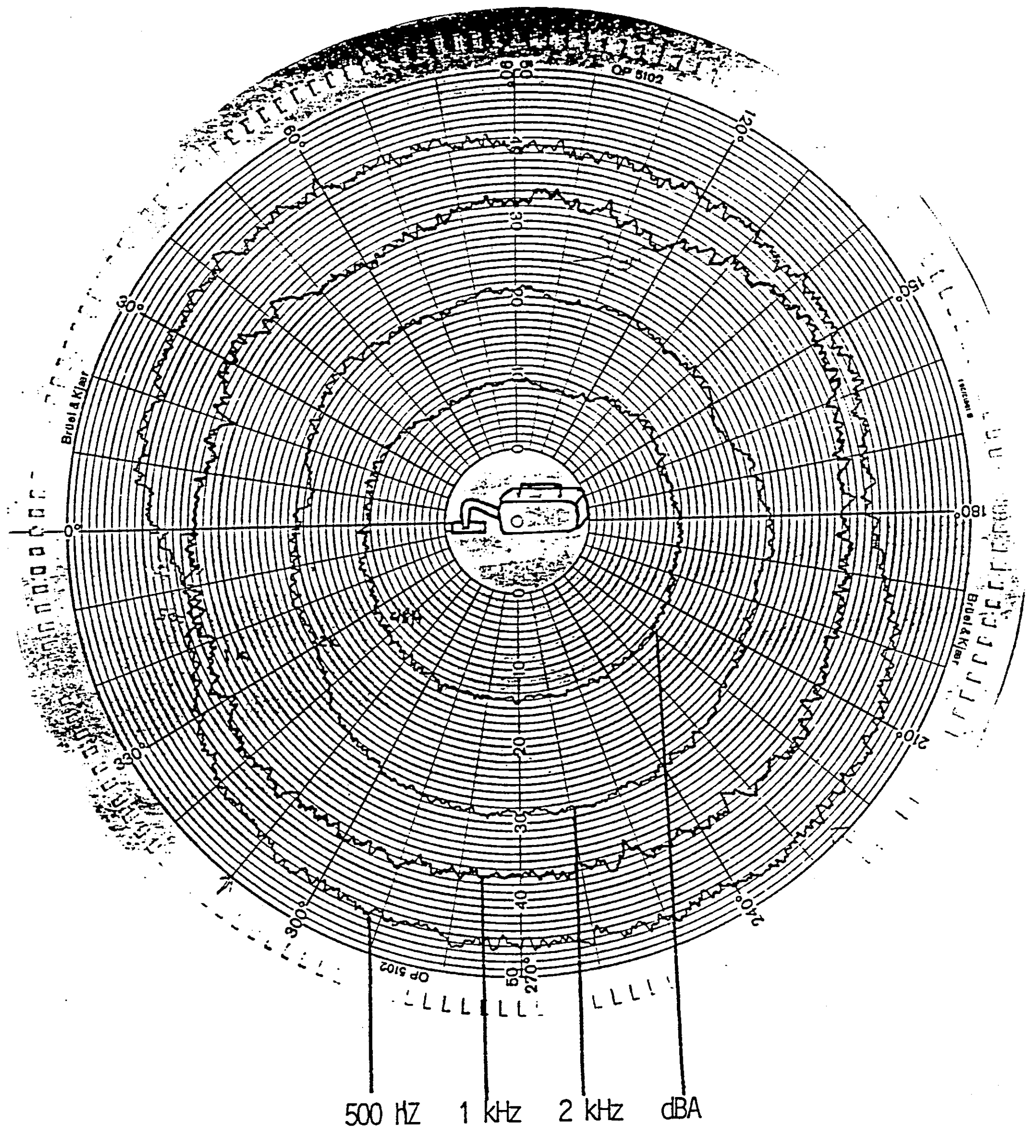
C.4 Philips TX2000 Liquidiser



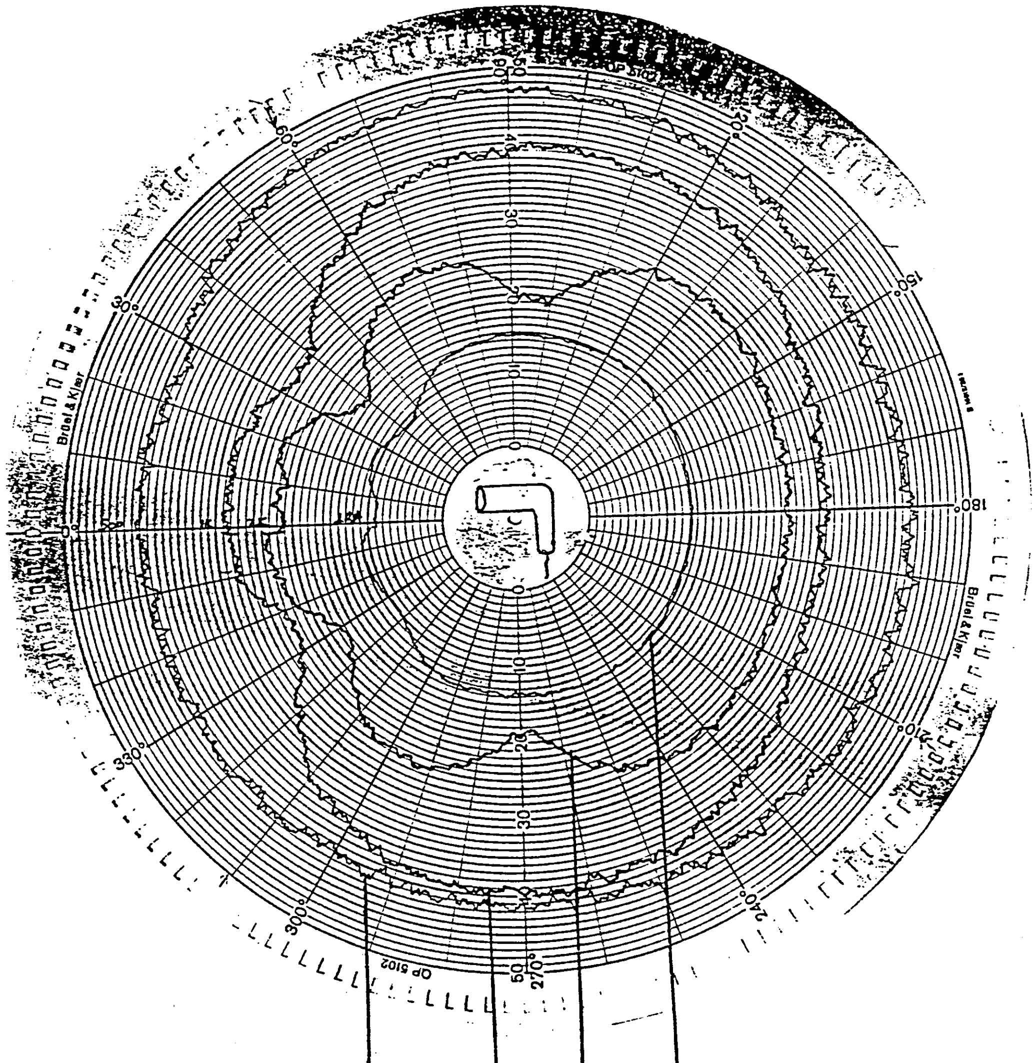
C.5 Hoover U2002 (upright) Vacuum Cleaner



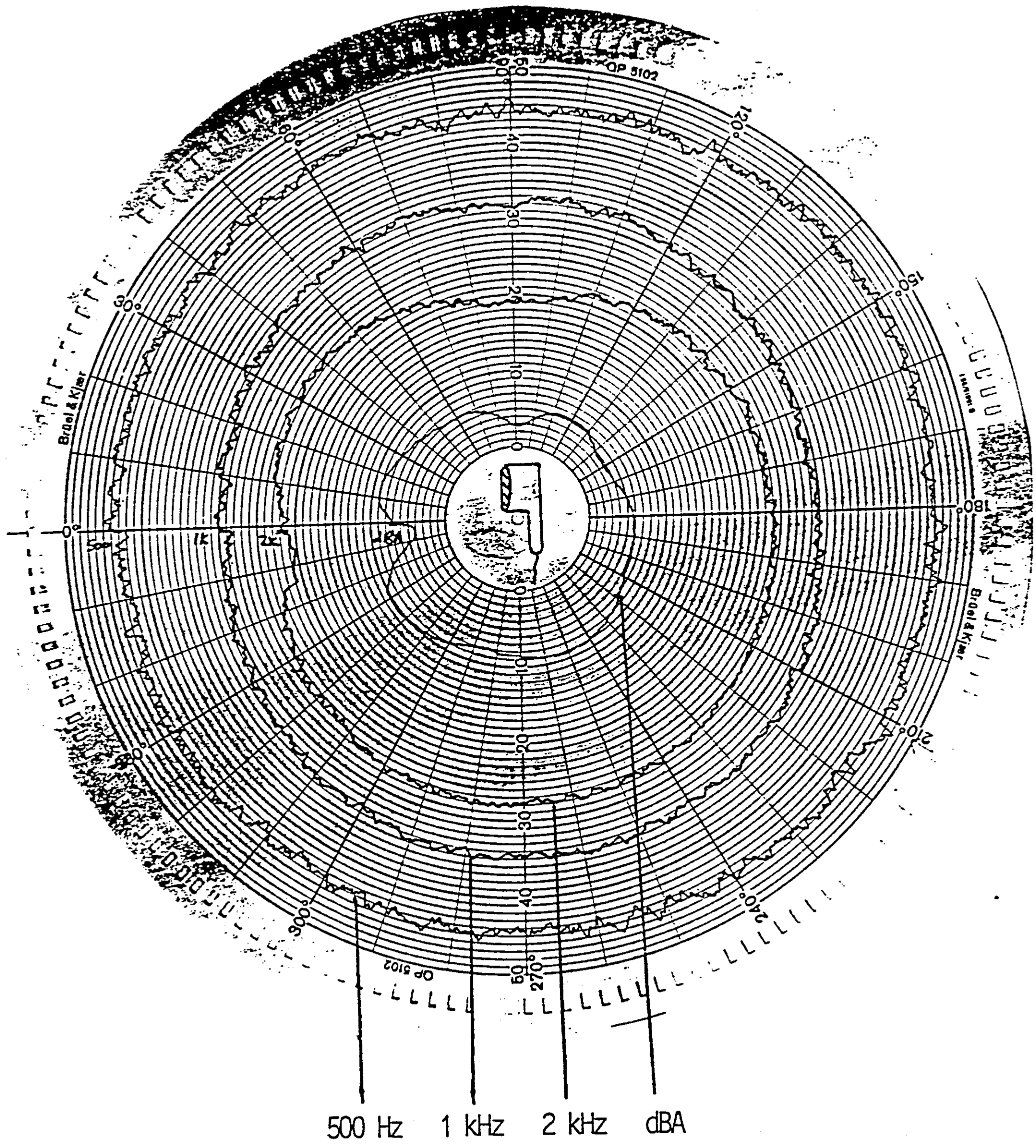
C.6 Electrolux ZA65 (cylinder) Vacuum Cleaner



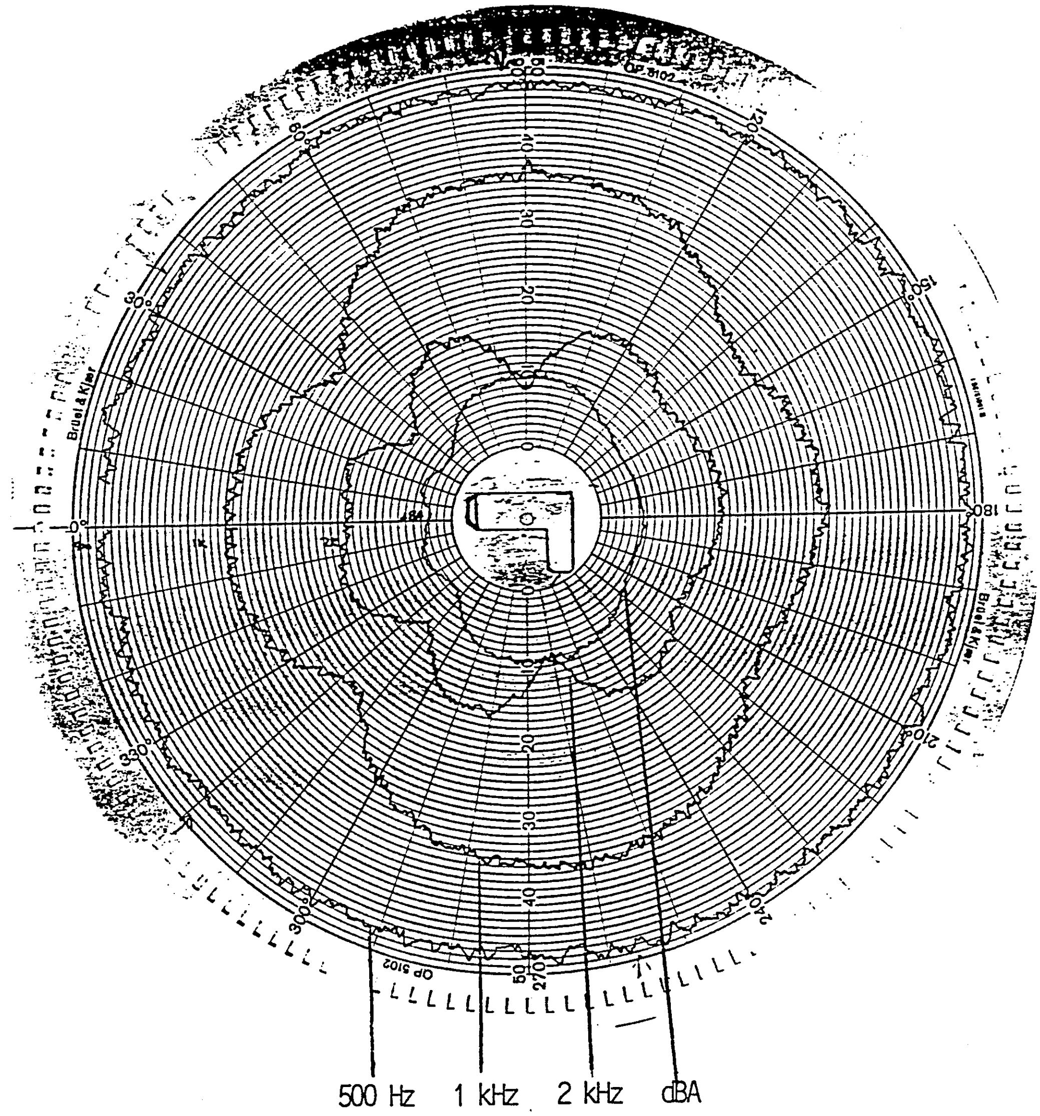
C.7 Braun Supercompact 1200 Hair Dryer - Speed 1



C.8 Boot MD2 Hair Dryer - Speed 2



C.9 Clairol 1200 Hair Dryer - Speed 1



Appendix D

A-weighted sound pressure levels of domestic appliances

This appendix presents the A-weighted sound pressure levels of the domestic appliances investigated during the course of this study, in the form of a series of tables, representing the A-weighted sound pressure level at each one-third octave centre frequency.

D.1 Hair Dryers

Table D.1 One-third octave A-weighted sound pressure levels for Hair Dryers I - VI

One-third octave centre freq (Hz)	HD I	HD II	HD III	HD IV	HD V	HD VI
100	39.5	39.9	36.3	38.0	36.3	36.9
125	30.9	31.4	29.0	30.5	29.2	29.0
160	46.0	46.5	42.6	43.9	42.4	41.9
200	37.4	37.4	35.6	36.7	39.0	37.6
250	38.4	53.1	36.0	37.8	37.3	40.0
315	35.1	39.2	34.1	41.8	37.6	47.8
400	41.7	44.3	41.3	43.0	46.7	50.0
500	38.8	47.5	41.8	43.5	47.9	55.1
630	38.9	46.3	46.1	48.1	51.1	55.8
800	44.4	54.5	55.5	60.8	65.0	64.2
1000	50.6	57.2	54.7	63.1	61.3	63.3
1250	48.8	57.8	49.7	53.5	55.9	64.3
1600	52.2	59.0	57.2	56.0	58.0	66.2
2000	51.6	57.6	57.6	62.1	55.1	61.2
2500	55.1	60.1	53.7	69.5	55.4	65.5
3150	52.8	60.2	56.0	60.6	59.4	63.9
4000	62.8	61.3	57.3	63.1	57.3	69.9
5000	52.6	65.5	57.6	69.9	53.3	62.5
6300	52.6	60.5	52.7	63.1	53.4	64.3
8000	49.9	57.2	51.1	62.8	49.8	57.9
10000	47.1	56.5	49.7	58.1	44.0	52.1

HD I = Boots MD2 - Speed 1

HD II = Boots MD2 - Speed 2

HD III = Moulinex 722 - Speed 1

HD IV = Moulinex 722 - Speed 2

HD V = Ronson Hotshot - Speed 1

HD VI = Ronson Hotshot - Speed 2

Table D.2 One-third octave A-weighted sound pressure levels for Hair Dryers VII - XI

One-third octave centre freq (Hz)	HD VII	HD VIII	HD IX	HD X	HD X1
100	39.8	39.7	36.1	42.7	40.2
125	31.4	31.4	27.8	32.0	38.8
160	45.5	46.1	42.3	45.5	43.3
200	37.5	38.2	34.0	39.3	42.1
250	38.7	44.0	44.5	40.8	42.6
315	36.5	41.0	36.1	51.7	42.6
400	43.4	47.8	42.1	45.4	46.2
500	43.7	48.2	43.3	50.5	52.0
630	43.7	48.0	43.9	53.2	58.2
800	55.4	56.0	53.6	55.7	60.0
1000	54.7	55.5	59.8	64.6	58.3
1250	55.8	62.3	59.1	64.5	56.3
1600	57.6	66.9	57.1	66.0	71.0
2000	59.7	65.3	60.8	69.3	61.6
2500	59.2	55.8	59.8	66.2	59.9
3150	59.4	66.2	56.5	67.5	61.2
4000	58.6	69.0	56.1	64.9	58.7
5000	57.1	65.4	54.7	63.7	60.5
6300	56.1	63.4	53.2	62.4	57.7
8000	50.9	58.0	54.0	60.5	57.3
10000	47.6	54.0	47.5	56.0	48.6

HD VII = Braun Compact 1500 - Speed 2

HD VIII = Braun Compact 1500 - Speed 3

HD IX = Braun Supercompact 1200 - Speed 1

HD X = Braun Supercompact 1200 - Speed 2

HD XI = Clairol 1200 - Speed 1

D.2 Vacuum Cleaners

Table D.3 One-third octave A-weighted sound pressure levels for Vacuum Cleaners I - IV

One-third octave centre freq (Hz)	VC I	VC II	VC III	VC IV
100	40.6	47.5	53.2	49.5
125	38.7	50.9	43.6	43.2
160	56.7	57.8	54.3	50.9
200	49.1	53.1	55.8	51.8
250	47.8	58.3	55.0	54.5
315	59.3	71.1	61.2	58.7
400	54.9	59.2	58.2	60.6
500	66.6	58.7	56.2	61.9
630	62.8	58.0	60.8	60.8
800	64.6	55.1	55.9	66.5
1000	64.3	56.7	56.0	66.6
1250	62.0	53.2	60.4	64.4
1600	63.5	53.6	56.5	63.1
2000	63.5	55.8	57.9	63.2
2500	60.4	57.0	55.8	64.1
3150	57.5	49.2	55.4	64.4
4000	54.6	55.2	54.1	61.3
5000	52.7	48.4	53.5	59.4
6300	49.7	46.3	51.4	58.0
8000	48.7	46.1	50.7	55.7
10000	44.0	44.5	49.5	52.4

VC I = Electrolux 520S

VC II = Electrolux ZA65

VC III = Electrolux 350E

VC IV = Kerstar C606 Supreme

Table D.4 One-third octave A-weighted sound pressure levels for Vacuum Cleaners V - VIII

One-third octave centre freq (Hz)	VC V	VC VI	VC VII	VC VIII
100	45.4	55.7	65.9	40.2
125	40.2	48.9	53.4	40.5
160	49.2	58.0	65.0	47.7
200	54.2	61.0	73.5	57.2
250	55.7	58.2	71.9	75.7
315	73.3	66.1	67.4	64.1
400	58.6	59.8	70.5	67.0
500	59.7	57.6	68.4	70.8
630	59.3	56.9	67.6	66.3
800	60.8	60.6	68.0	66.7
1000	57.8	59.5	67.4	66.7
1250	63.2	62.2	67.5	71.7
1600	64.6	56.9	68.9	71.7
2000	62.7	59.5	66.2	69.4
2500	62.2	57.9	67.5	68.7
3150	61.1	57.6	64.2	65.9
4000	59.6	56.8	61.9	64.5
5000	56.8	56.2	60.0	61.5
6300	55.6	53.5	59.9	59.2
8000	53.2	51.9	54.9	52.3
10000	50.1	48.8	48.6	80.9

VC V = Electrolux 345

VC VI = Electrolux 350E - Superboost

VC VII = Hoover U2002

VC VIII = Hoover 119

D.3 Food Mixers

Table D.5 One-third octave A-weighted sound pressure levels for Food Mixers I - IV

One-third octave centre freq (Hz)	FM I	FM II	FM III	FM IV
100	38.8	40.1	37.9	36.8
125	43.2	35.4	41.9	42.0
160	47.7	46.9	49.3	56.7
200	57.8	40.9	50.1	47.3
250	53.5	49.0	49.4	53.6
315	47.7	51.4	46.7	57.3
400	47.4	62.7	52.3	65.4
500	48.1	64.1	52.7	62.6
630	50.7	55.8	54.0	58.8
800	51.6	56.8	52.8	64.3
1000	54.6	60.0	55.9	63.2
1250	58.7	61.0	58.3	64.3
1600	58.5	61.5	57.6	74.5
2000	57.9	63.2	61.4	70.3
2500	57.9	63.8	58.2	64.9
3150	56.7	67.2	57.5	64.4
4000	57.0	61.0	56.2	59.4
5000	55.7	61.8	52.6	57.5
6300	53.3	58.7	49.0	54.9
8000	54.8	54.3	45.9	52.5
10000	52.3	51.4	43.4	47.5

FM I = Philips HR1907 Speed - 1

FM II = Kenwood Mini A345 - Speed 2

FM III = Philips HM3060 - Speed 1

FM IV = Kenwood Chef A901 - Speed 4

D.4 Liquidisers

Table D.6 One-third octave A-weighted sound pressure levels for Liquidisers I - IV

One-third octave centre freq (Hz)	LIQ I	LIQ II	LIQ III	LIQ IV
100	39.2	37.4	37.6	43.1
125	44.6	28.5	36.5	43.8
160	49.5	42.3	45.4	55.1
200	55.1	43.4	51.9	51.0
250	56.1	62.2	72.9	51.7
315	56.6	46.4	53.4	59.5
400	63.4	53.9	59.9	64.6
500	61.6	60.7	80.3	65.8
630	57.8	57.0	64.5	65.7
800	66.3	55.4	63.6	65.5
1000	68.1	61.9	64.8	67.2
1250	65.4	62.8	69.8	72.6
1600	68.1	70.0	70.2	73.0
2000	69.7	70.3	71.0	73.6
2500	68.9	66.2	71.0	72.7
3150	66.6	64.9	72.1	72.2
4000	66.6	65.4	67.2	70.3
5000	62.2	64.0	66.4	65.5
6300	57.0	62.7	64.7	60.9
8000	53.3	56.8	58.4	57.2
10000	50.1	51.9	54.4	53.1

LIQ I = Philips TX2000 - Speed 1

LIQ II = Moulinex 530

LIQ III = Moulinex 241.2

LIQ IV = Kenwood Chef A901 and Liquidiser Attachment

D.5 Food Processors

Table D.7 One-third octave A-weighted sound pressure levels for Food Processors I - III

One-third octave centre freq (Hz)	FP I	FP II	FP III
100	37.4	37.8	37.3
125	35.8	36.9	46.8
160	44.3	45.1	47.1
200	39.9	43.5	46.5
250	54.4	61.5	55.3
315	44.8	52.5	64.9
400	46.4	49.9	62.3
500	50.2	53.9	62.1
630	50.6	55.5	64.2
800	52.9	60.9	64.2
1000	60.9	65.3	63.3
1250	60.1	67.7	62.4
1600	66.2	67.5	66.6
2000	54.6	69,7	67.9
2500	55.2	75.0	67.5
3150	55.4	73.6	70.6
4000	49.7	72.8	82.4
5000	48.6	68.6	67.2
6300	48.9	64.4	60.6
8000	49.8	57.5	63.7
10000	45.5	52.3	56.7

FP I = Prestige L2001

FP II = Robot Chef - RC3

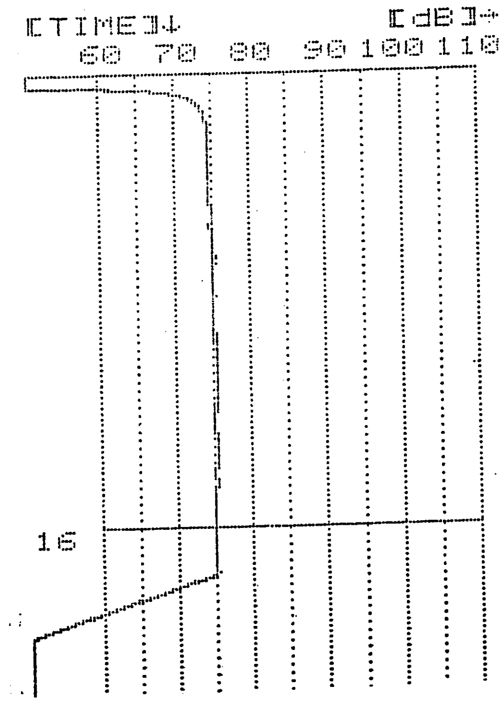
FP III = Braun MC-1

Appendix E

Time Histories

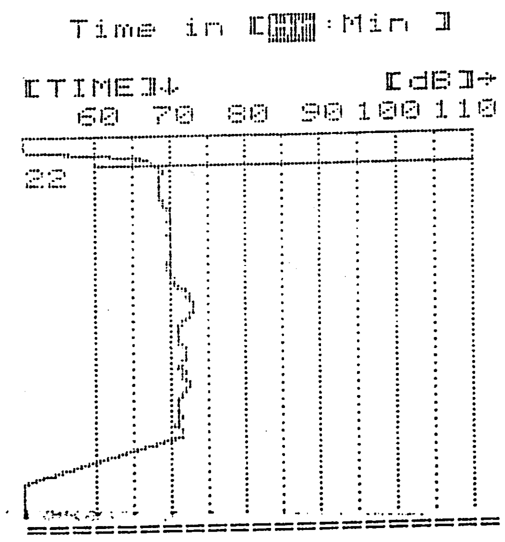
Experiments, described in Chapter 5, section 5.2.3 were carried out to identify appliances whose noise emission level varied with time. The criteria adopted for identifying such appliances was in cases where values of maximum A-weighted sound pressure level and equivalent continuous A-weighted sound pressure level differed by more than 2 dB. The plots included in this appendix are for appliances displaying variations in their noise emission level. The time histories were measured over approximately 20 seconds. The first plot, that for the Braun 1200 Supercompact Hair Dryer - Speed 1 is included for comparison purposes. The noise emission level of this appliance is considered to be steady.

E.1 Braun 1200 Supercompact Hair Dryer - Speed 1



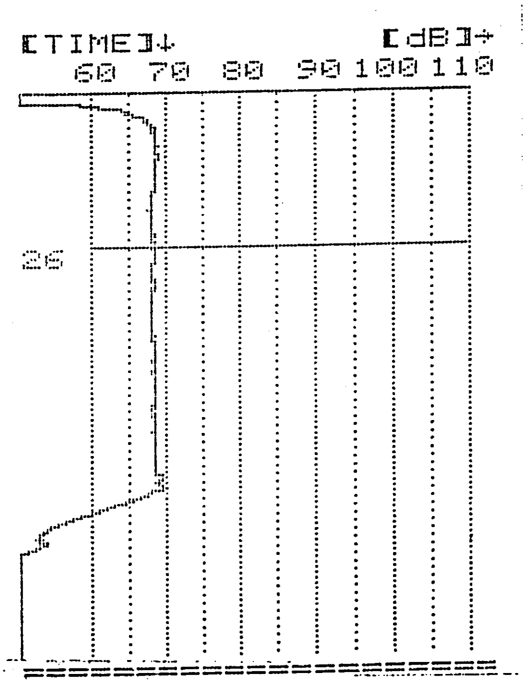
A-weighted sound pressure level vs time (seconds)

E.2 Boots MD2 Hair Dryer - Speed 2



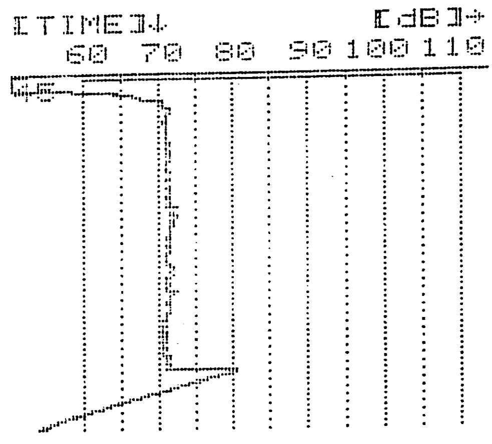
A-weighted sound pressure level vs time (seconds)

E.3 Electrolux ZA65 Vacuum Cleaner



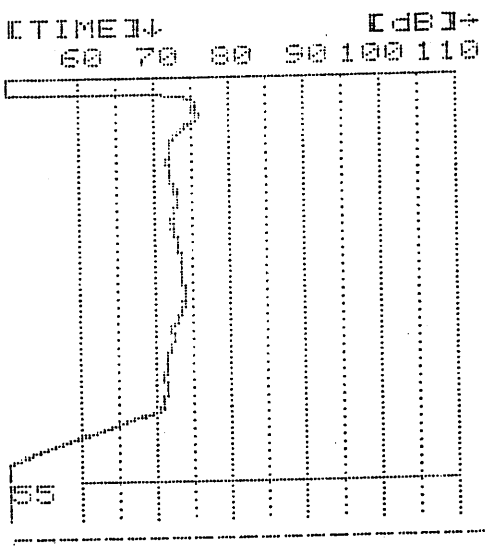
A-weighted sound pressure level vs time (seconds)

E.4 Kerstar C606 Supreme Vacuum Cleaner



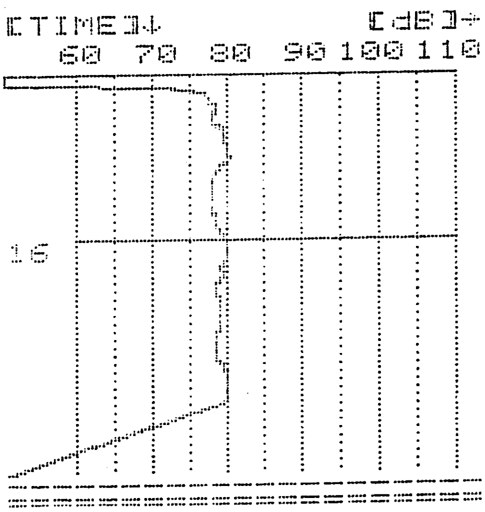
A-weighted sound pressure level vs time (seconds)

E.5 Prestige L2001 Food Processor



A-weighted sound pressure level vs time (seconds)

E.6 Braun MC - 1 Food Processor



A-weighted sound pressure level vs time (seconds)

Appendix F

Audiometry Testing

A Madsen Electronic Memory Threshold Audiometer MTA 86 was used to test for normal hearing of the subjects. A brief description of the equipment and the program used is given below.

F.1 General Description

The Madsen MTA86 Memory Threshold Audiometer is specially designed for applications in industry, schools etc. All results are recorded by means of the built-in alphanumeric printer. The instrument contains programs, which allow the audiometer to perform fully automatic threshold tests, automatic screening tests, manual tone audiometry, any mixture of the mentioned tests and a complete analysis of the results. After a test is performed, the results are automatically recorded on strip-chart-paper and include instrument data, calibration date and type, date of test, patient and operator number. The technical specifications are as follows:

Hearing Level Range:	0 to +95 dB in 5 dB steps
Frequencies:	250-500-1000-2000-3000-4000-6000-8000Hz
Programs:	Automatic Threshold Automatic Screening Manual Operation
Memory Capacity:	74 kbits
Printer:	Alphanumeric 20 Characters per line Writing Speed 2 lines per sec. Electrosensitive metallized paper.
Power Supply:	AC 50/60 Hz 110 or 220 V
Calibration:	ISO-R389-1970/B.S.2497/ANSI S3.6-1969
Distortion:	Less than 1%
Accuracy:	Frequencies: Better than +/- 1% Hearing Level: Within +/- 3 db

F.2 Audiometric Program Used

An Automatic Threshold Program was used to find the pure tone audiogram in an automatic way to avoid the human influence of the operator. To ensure the greatest possible reliability of this test, the respective thresholds are crossed several times and a number of precautions are taken not to accept invalid or impossible patient responses. After the test is accomplished the results are recorded on paper and analyzed.

The principle of the program is that the first tone is presented at a relatively high hearing level of 50 dB at 1000 Hz to the left ear. If the patient responds, then the intensity is decreased in 10 dB steps, and if responded to, then further decreases in 10 dB steps occur.

If the patient does not respond to the first presentation at 50 dB, then the intensity increases in 20 dB steps until the first patient-response occurs. Then follows the decrease in 10 dB steps as described above.

At the moment where the patient does not respond to a tone presentation during the 10 dB decrease sequence, the program starts to find the threshold. 5 dB increases are presented until a response occurs. Then another 10 dB decrease and 5 dB increases occur until a response is elicited. When the threshold is evaluated the information is stored in a memory and the program continues to the next frequency, where the initial intensity will be the threshold from the previous frequency plus 20 dB.

Appendix G

Reverberation time measurements of experimental room

The subjective experiments were carried out in the living room and kitchen of a detached house, built in 1960 with standard cavity brick structure. The house provides temporary accommodation for visiting lecturers and newly appointed members of staff. The dimensions of the living room and kitchen can be seen in Figure 6.1 in Chapter 6.

The reverberation times (being defined as the time required for the level of sound to fall by 60 dB) of the living room and kitchen were measured because, along with details of the room's volume and surface areas, it enables calculation of the absorption that will occur in the room for certain frequency bands. One third octave white noise up to 20 kHz was generated by a Bruel and Kjaer noise generator type 1405, filtered through a Bruel and Kjaer band pass filter set Type 1614. The sound was amplified by a H and H electronic amplifier, before being emitted through an Electro Voice S1202 two way stage system speaker. The sound generating equipment was situated towards the centre of each room.

The sound receiving equipment consisted of a Bruel and Kjaer half inch microphone capsule type 4165 and associated Bruel and Kjaer preamplifier Type 2639, powered by a Bruel and Kjaer two channel microphone power supply. The signal was transmitted, via a Bruel and Kjaer spectrum shaper (to eliminate background noise), to a Bruel and Kjaer measuring amplifier and was recorded using a Bruel and Kjaer Level Recorder Type 2305. The level recorder was used with a 50 dB potentiometer, a writing speed of 500/1000 mm per second, 100 mm per sec paper speed, lower limiting frequency of 50 Hz and set to RMS function.

As the signal was stopped, using the 'generator stop' facility of the noise generator, the decay in sound level was recorded on the paper output of the chart level recorder. This process was repeated for one-third octave band central frequencies from 100 Hz to 4 kHz at three different central measuring positions in each room. The microphone was always positioned at a height approximately 1.2m above the floor.

Using the data for the three measuring positions in each room, a simple arithmetic average can be determined, giving a range of reverberation time measurements for one-third octave band central frequencies from 100 Hz to 4 kHz.

According to Burgess and Utley [109] the average reverberation time for a

British living room is in the range 0.27 to 0.38 sec depending on the frequency. It can be seen in Table G.1 that the reverberation times ranged from 0.27 to 0.6 secs, again depending on the frequency of interest. These are slightly higher than average for a living room. However, this could possibly be attributed to the furnishings of the living room. Being only temporary accommodation for its residents, the room is furnished much more sparsely than most living rooms. The carpet is thinner than normal domestic room carpets, and instead of a sofa, there are four office-type wooden arm chairs. The curtains are also considerably thinner than normal domestic curtains. The room contains a table, four arm chairs, 3 dining chairs and a television. There are no plants, lamps or other items one would normally find in a living room. Hence it is only to be expected that reverberation times would be longer than normal.

Having obtained reverberation time measurements, it is possible to calculate information about the room's absorption. The total sound absorption of the room can be calculated from

$$A = \frac{0.161V}{T} \tag{G.1}$$

where V is the volume of the room and T the reverberation time at any one-third octave band central frequency. The average absorption α may then be determined from

$$\alpha = \frac{A}{S} \tag{G.2}$$

where S is the surface area of the room. Thus from the reverberation time it is possible to calculate the amount of absorption that will occur in certain frequency bands in the room. Table G.1 and Table G.2 show the average absorption for each one-third octave frequency band of interest, for the living room and kitchen.

Table G.1 Reverberation times of the Living Room.

Freq Hz	1	2	3	Average	α
100	0.36	0.39	0.41	0.39	0.205
125	0.66	0.54	0.60	0.60	0.132
160	0.51	0.60	0.39	0.50	0.158
200	0.42	0.60	0.57	0.53	0.149
250	0.54	0.42	0.42	0.46	0.172
315	0.39	0.36	0.37	0.37	0.212
400	0.36	0.39	0.30	0.35	0.226
500	0.45	0.42	0.45	0.44	0.180
630	0.33	0.33	0.39	0.35	0.226
800	0.39	0.37	0.30	0.35	0.226
1000	0.30	0.30	0.36	0.32	0.247
1250	0.30	0.30	0.36	0.32	0.247
1600	0.36	0.35	0.42	0.38	0.210
2000	0.30	0.42	0.41	0.38	0.210
2500	0.36	0.36	0.39	0.37	0.214
3150	0.27	0.21	0.36	0.25	0.316
4000	00.48	0.30	0.48	0.42	0.188

Where: Position 1=Microphone facing window. Position 2 = Microphone facing television. Position 3 = Microphone facing Wall.
Volume=26.532m^3. Surface area = 54.03 m^2

Table G.2 Reverberation times of the kitchen.

Freq Hz	1	2	3	Average	α
100	0.48	0.36	0.60	0.48	0.161
125	0.30	0.33	0.45	0.36	0.215
160	0.42	0.30	0.42	0.38	0.204
200	0.48	0.27	0.42	0.39	0.198
250	0.39	0.27	0.36	0.34	0.228
315	0.42	0.33	0.36	0.37	0.209
400	0.24	0.36	0.39	0.33	0.234
500	0.39	0.24	0.42	0.35	0.221
630	0.42	0.30	0.39	0.37	0.209
800	0.42	0.30	0.42	0.38	0.204
1000	0.45	0.36	0.42	0.41	0.189
1250	0.48	0.42	0.42	0.44	0.176
1600	0.36	0.36	0.36	0.36	0.215
2000	0.36	0.36	0.36	0.36	0.215
2500	0.36	0.39	0.33	0.36	0.215
3150	0.30	0.33	0.45	0.36	0.215
4000	0.39	0.39	0.39	0.39	0.198

Where: Position 1 = Microphone facing Fridge. Position 2 = Microphone facing Window. Position 3 = Microphone facing Larder. Volume = 14.064 m^3. Surface Area = 29.272 m^2.

Appendix H

Response Sheets

This appendix contains the response sheets used during the subjective experiments to obtain noisiness ratings on a 7 point scale. Three different response sheets were used, during the course of the subjective experimental work.

- Response Sheet 1 - This response sheet was used during the subjective experiments associated with Hypothesis 3 (investigation of difference in noisiness ratings between subjects as users and listeners of the appliances).
- Response Sheet 2 - This response sheet was used during the experiments associated with Hypotheses 1, 2, 3 and 4 (standard listener response sheet when four appliances were presented to subjects).
- Response Sheet 3 - This response sheet was used during the experiments associated with Hypotheses 5 - 14 (standard listener response sheet for experiments in which six appliances were presented to subjects).

H.1 Response Sheet 1

LISTENER RESPONSE SHEET INSTRUCTIONS

DATE: ______________________ SESSION NUMBER: ______________

NAME: ______________________ DEPARTMENT: ______________

OCCUPATION: ____

During the test you will hear four domestic appliances one at a time.

You are asked to rate the sound from each appliance according to how noisy you consider it to be by circling the appropriate number on the scale 1-7:

Very Quiet 1 2 3 4 5 6 7 Extremely Noisy

For example, if you consider the sound to be extremely noisy, then you would circle 6 or 7; if you consider the sound to be very quiet, then you would circle 1 or 2; if you consider the sound to be neither very quiet or extremely noisy, then you would circle 4.

Please rate each sound immediately after it has finished. It must be emphasised that there are no right or wrong answers - we require your own judgement of the noise of each appliance.

SOUND No	RATING No	1 = Very Quiet			7 = Extremely Noisy		
1	1	2	3	4	5	6	7
2	1	2	3	4	5	6	7
3	1	2	3	4	5	6	7
4	1	2	3	4	5	6	7

H.2 Response Sheet 2

LISTENER RESPONSE SHEET INSTRUCTIONS

DATE: ______________________ SESSION NUMBER: ______________________

NAME: ______________________ DEPARTMENT: ______________________

OCCUPATION: ____

During the test you will hear six domestic appliances one at a time.

You are asked to rate the sound from each appliance according to how noisy you consider it to be by circling the appropriate number on the scale 1-7:

Very Quiet 1 2 3 4 5 6 7 Extremely Noisy

For example, if you consider the sound to be extremely noisy, then you would circle 6 or 7; if you consider the sound to be very quiet, then you would circle 1 or 2; if you consider the sound to be neither very quiet or extremely noisy, then you would circle 4.

Please rate each sound immediately after it has finished. It must be emphasised that there are no right or wrong answers - we require your own judgement of the noise of each appliance.

SOUND No	RATING No	1 = Very Quiet			7 = Extremely Noisy		
1	1	2	3	4	5	6	7
2	1	2	3	4	5	6	7
3	1	2	3	4	5	6	7
4	1	2	3	4	5	6	7
5	1	2	3	4	5	6	7
6	1	2	3	4	5	6	7

H.3 Response Sheet 3

USER RESPONSE SHEET INSTRUCTIONS

DATE:______________________ SESSION NUMBER: ______________

NAME: ______________________ DEPARTMENT: ________________

OCCUPATION:____

During the test you will use four domestic appliances, one at a time.

You are asked to rate the sound from each appliance according to how noisy you consider it to be by circling the appropriate number on the scale 1-7:

Very Quiet 1 2 3 4 5 6 7 Extremely Noisy

For example, if you consider the sound to be extremely noisy, then you would circle 6 or 7; if you consider the sound to be very quiet, then you would circle 1 or 2; if you consider the sound to be neither very quiet or extremely noisy, then you would circle 4.

Please rate each sound immediately after it has finished. It must be emphasised that there are no right or wrong answers - we require your own judgement of the noise of each appliance.

SOUND No	RATING No	1 = Very Quiet			7 = Extremely Noisy		
1	1	2	3	4	5	6	7
2	1	2	3	4	5	6	7
3	1	2	3	4	5	6	7
4	1	2	3	4	5	6	7

Appendix I

Questionnaire 1

QUESTIONNAIRE NUMBER 1

DATE: ____________________ SESSION NO ____________________

NAME: ____

Thank you very much for your co-operation in this test. We would be grateful if you could now complete the following questionnaire.

1(a) Which of the following electrical appliances do you have in your home?

A Can Cpener	☐	G Food Waste Disposal Unit	☐	M Sewing Machine	☐
B Coffee Mill	☐	H Hair Drier	☐	N Shaver	☐
C Dishwasher	☐	I Kettle	☐	O Tumble Drier	☐
D Fan Heater	☐	J Knife	☐	P Vacuum Cleaner	☐
E Food Mixer	☐	K Knife Sharpener	☐	Q Washing Machine	☐
F Food Processor	☐	L Liquidiser	☐		

1(b) Of the appliances listed above, which 4 are the most frequently used in your household? Please write the appropriate letters in the boxes.

☐☐☐☐

1(c) Of these 4, could you please list the things that you LIKE about them? Put the appropriate letters in the boxes.

APPLIANCE: ☐ ....

☐ ....

☐ ....

☐ ....

1(d) Of the same 4 appliances, could you please list the things that you DISLIKE about them? Put the appropriate letters in the boxes.

APPLIANCE: ☐ ....

☐ ....

☐ ....

☐ ....

1(e) How willing are you to put up with the 4 appliances' noise?

Not Willing 1 2 3 4 5 6 7 Very Willing

APPLIANCE: ☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

1(f) How noisy do you find the 4 appliances you mentioned in question 1(b)? Please ring the appropriate number.

Very Quiet 1 2 3 4 5 6 7 Extremely Noisy

APPLIANCE: ☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

☐ 1 2 3 4 5 6 7

1(g) Does the noise from domestic appliances bother or annoy you?

Very much ☐
Moderately ☐
A little ☐
Not at all ☐

2(a) Using the given categories, could you complete the following table (by answering the questions below) for those appliances you regularly use in your home.

(i) What make is the appliance?

(ii) What age is the appliance?
< 1 year   1-5 years   5-10 years   > 10 years

(iii) How useful is the appliance <u>to you</u> in your home?
Very useful   Useful   Quite useful   Not useful

(iv) How many times do you use it per week?
Eg, once, twice, etc

(v) For how many minutes do you use it per week? (approximately)

(vi) Do you consider it to be noisy? Please rate according to the following scale:

Very Quiet 1 2 3 4 5 6 7 Extremely Noisy

(vii) Can you list the other people who use the appliance in your home

	Make (i)	Age (ii)	Usefulness (iii)	No of times used (iv)	No of minutes (v)	Noise Rating (vi)	People using it (vii)
Vacuum Cleaner							
Hair Drier							
Liquidiser							
Food Mixer/ Processor							

2(b) Do you believe manufacturers are concerned about the noise from their appliances?

Yes ☐
No ☐
Not Sure ☐

3(a) How much time per week do you spend inside your home? (approximately)

____

3(b) How do you spend your time inside your home?

____

____

3(c) What are your hobbies?

____

____

____

4(a) Are you ever disturbed by noise from your neighbours? YES/NO
If YES - could you list the noises you hear.

....

....

4(b) In general, does noise ever bother, annoy or disturb you in any way?

- Very often ☐
- Fairly often ☐
- Occasionally ☐
- Hardly ever ☐
- Don't know ☐

4(c) On the whole, would you say there is too much or too little fuss made about noise nowadays?

- Too much fuss ☐
- About right ☐
- Too little fuss ☐
- Don't know ☐

4(d) Would you say you are more or less sensitive than other people to noise?

- More sensitive ☐
- Less sensitive ☐
- The same ☐
- Don't know ☐

4(e) How far would you agree or disagree with the people who say 'noise is one of the biggest nuisances of modern times'?

- Strongly agree ☐
- Agree ☐
- Disagree ☐
- Disagree strongly ☐
- Don't know ☐

4(f) Could you sum up your opinion by saying whether you find noise

- Very disturbing ☐
- Disturbing ☐
- A little disturbing ☐
- Not at all disturbing ☐

5(a) In what year were you born? ____________

5(b) Sex M / F

5(c) What is your present occupation? ______________________________

Is that full or part time?

	Full time	☐
	Part time	☐

5(d) How old were you when you finished your full-time education

	14 or under	☐
	15	☐
	16 - 18	☐
	After College/Univ./Poly	☐
	After Post Graduate Work	☐

5(e) In what type of house do you live?

	Flat	☐
	Terrace	☐
	Semi-detached	☐
	Detached	☐

I.1 Questionnaire 1 - A summary of results

A summary of the results of Questionnaire 1 are presented in this appendix, in the order in which the questions are asked on the questionnaire.

I.2 Questions 1a to 1g

I.2.1 Which....electrical appliances do you have in your home?

Table I.1 presents the appliances owned by subjects.

Table I.1 Electrical appliances owned by subjects.

Appliance	No. of subjects N=32	% of total
Can Opener	2	6.3
Coffee Mill	5	15.6
Dishwasher	5	15.6
Fan Heater	11	34.4
Food Mixer	21	65.6
Food Processor	16	50.0
Hair Dryer	30	93.8
Kettle	30	93.8
Knife	6	18.8
Knife Sharpener	1	3.1
Liquidiser	16	50.0
Sewing Machine	23	71.9
Shaver	15	46.9
Tumble Dryer	9	28.1
Vacuum Cleaner	31	96.9
Washing Machine	26	81.3

It can be seen that most subjects owned the noisiest appliances - namely hair dryers, vacuum cleaners and washing machines. Although most subjects possessed a kettle, the kettle is not among the noisiest appliances.

I.2.2 Of the appliances listed above, which 4 are the most frequently used in your household?

Table I.2 presents the appliances most frequently used by subjects in their homes.

Table I.2 Appliances most frequently used by subjects.

Appliance	No. of subjects N=32	% of total citing this appliance
Dishwasher	2	40.0
Fan Heater	4	36.4
Food Mixer	3	14.3
Food Processor	4	25.0
Hair Dryer	19	63.3
Kettle	22	73.3
Shaver	10	66.7
Tumble Dryer	5	55.6
Vacuum Cleaner	27	87.1
Washing Machine	26	100

Again, the most frequently used appliances were among the noisiest - washing machines, vacuum cleaners and hair dryers. Liquidisers, food mixers and food processors, although among the noisiest appliances, were not among those most frequently used by subjects.

I.2.3 For the four most frequently used appliances, could you please list the things that you LIKE about them?

Table I.3 presents the reasons why subjects liked their most frequently used appliances.

I.2.4 For the four most frequently used appliances could you please list the things that you DISLIKE about them?

The reasons for disliking the appliances most frequently used are presented in Table I.4.

Table I.3 Reasons for liking the appliances most frequently used - Percentage of respondents citing each reason.

Appliance	Design	Efficiency	Quietness	Convenience	Nothing
Dishwasher		50		50	
Fan Heater		50		25	25
Food Mixer		33.3		66.6	
Food Processor		100			
Hair Dryer	5.3	57.9	5.3	21.1	10.5
Kettle	4.5	45.5	9.1	36.4	4.5
Shaver		60		20	20
Tumble Dryer		40		60	
Vacuum Cleaner	7.4	59.3	7.4	14.8	11.1
Washing Machine	3.8	69.2	3.8	15.4	7.7

Table I.4 Reasons for disliking the appliances most frequently used - Percentage of respondents citing each reason.

Appliance	Bad Design	Not Efficient	Noisy	Heavy	Nothing
Dishwasher			100		
Fan Heater	25		25		50
Food Mixer			66.6	33.3	
Food Processor			75		25
Hair Dryer	10.5		47.4	5.3	36.8
Kettle	31.8	9.1	18.2		40.9
Shaver	30	10	30		30
Tumble Dryer	40		40		20
Vacuum Cleaner	14.8	7.4	48.1	3.7	25.9
Washing Machine	26.9	7.7	50	3.7	15.4

Note 'design' and 'efficiency', good or bad, were among the reasons cited for like and dislike of an appliance. 'Convenience' was a popular reason for liking an appliance. The noise of an appliance was the most frequently cited cause for disliking an appliance, although mention of this is probably not spontaneous as the questionnaire was completed in the middle of the session after subjects had already been rating the noisiness of appliances. The questionnaire could have been completed at the commencement of the experiment, although the danger then is that it could bias the noisiness ratings - asking questions about noise in a questionnaire could give them preconceived ideas which would be reflected in exaggerated noisiness ratings.

I.2.5 How willing are you to put up with the (appliances most frequently used) noise?

Table I.5 presents the percentage of responses to each category of willingness to put up with the noise of the most frequently used appliance (where 1 = Not willing, and 7 = Very willing).

Table I.5 Willingness to put up with the noise of the most frequently used appliances - Percentage of responses to each category.

Appliance	1	2	3	4	5	6	7
Dishwasher		50			50		
Fan Heater		25	25		25	25	
Food Mixer		33.3	33.3				33.3
Food Processor			25			50	27
Hair Dryer		10.5	15.8	10.5	31.6	5.2	26.3
Kettle	4.5		13.6		9.1	9.1	63.6
Shaver		30		10	30	10	20
Tumble Dryer	40	20	20		20		
Vacuum Cleaner	11.1	18.5	14.8	14.8	14.8	7.4	18.5
Washing Machine	3.8	3.8	11.5	11.5	30.8	15.4	19.2

In most cases over half subjects were moderately or very willing to put up with their appliance's noise. The exceptions to this are for the food mixer and tumble dryer, where over half subjects rated 1 - 3 on the scale. It would appear that the noise level is a mere nuisance compared to the labour saving benefits offered by the appliances.

I.2.6 How noisy do you find the appliance most frequently used?

Table I.6 presents the subjects' rating of the noisiness of the appliances most frequently used (where 1 = Very Quiet and 7 = Extremely Noisy).

Table I.6 Noisiness ratings for the appliances most frequently used - Percentage of responses for each category.

Appliance	1	2	3	4	5	6	7
Dishwasher			50	50			
Fan Heater			25	25	25	25	
Food Mixer				33.3		33.3	33.3
Food Processor		25			25	25	25
Hair Dryer		21.1	10.5	15.8	31.6	15.8	5.3
Kettle	36.4	18.2	9.1	13.6	13.6	4.5	4.5
Shaver	10	30	50			10	
Tumble Dryer				40	20		40
Vacuum Cleaner		3.7	11.1	14.8	29.6	25.9	14.8
Washing Machine	3.8	7.7	3.8	30.8	30.8	23.1	

In most cases over half subjects rated their appliance from 4 - 7 (moderately to extremely noisy). Three exceptions to this were the ratings for dishwasher, kettle and shaver, which are not included among the noisy small appliances.

I.2.7 Does the noise from domestic appliances bother or annoy you?

The percentage of responses to each category are presented in Table I.7.

Table I.7 Percentage of responses to the question - Does the noise from domestic appliances bother or annoy you?

Category	% of responses
Very much	18.8
Moderately	40.6
A little	31.3
Not at all	9.4

Over half the subjects were very much or moderately bothered or annoyed by the noise from domestic appliances, and 90 % were more than a little bothered or annoyed. Only a small percentage of subjects found the noise level emission of domestic appliance not annoying or bothersome.

I.3 Questions 2a to 2b

The subjects were then asked to give information about four types of appliances in their homes (if applicable): Hair dryer, vacuum cleaner, liquidiser and food mixer/processor.

I.3.1 The age of the appliance

Table I.8 presents the various ages of appliances owned by subjects.

Table I.8 Age of the appliances - Percentage of responses.

Appliance	<1 yr	1 - 5 yr	5 - 10 yr	> 10 yr	Not applicable
Vacuum Cleaner	28.1	34.4	12.5	18.8	6.3
Hair Dryer	12.5	62.5	15.6	3.1	6.3
Liquidiser	3.1	21.9	21.9	6.3	46.9
Food Mixer	12.5	34.4	21.9	6.25	25

I.3.2 How useful is the appliance to you in your home?

Table I.9 presents the percentage of responses to each category of usefulness for each appliance.

Table I.9 Usefulness of the appliances - Percentage of responses to each category.

Appliance	Very useful	Useful	Quite useful	Not useful
Vacuum Cleaner	60	20	13	7
Hair Dryer	30.8	19.2	30.8	19.2
Liquidiser	6.25	25	56.3	12.5
Food Mixer	13.6	40.9	36.4	9.1

Usefulness ratings are quite widespread along the scale. The largest percentage of responses for the vacuum cleaner was for 'very useful'; for the hair dryer it was equally 'quite useful' and 'very useful'; for the liquidiser 'quite useful', and for the food mixer 'useful'.

I.3.3 How many times do you use the appliances per week?

Table I.10 presents the percentage of responses for the question -How many times do you use the appliances per week.

Table I.10 Number of times the appliances are used per week - Percentage of responses.

Appliance	1	2	3	4	5	6	7
Vacuum Cleaner	63.3	13.3	6.7	6.7	3.3		6.7
Hair Dryer	34.6	23.1	15.4	15.4			11.5
Liquidiser	87.5	12.5					
Food Mixer	72.7	18.3	4.5	4.5			

Most appliances are not used more than four times a week - most are only used once a week. The exception to this is for the hair dryer, where some subjects use it every day.

I.3.4 For how many minutes do you use the appliances per week?

The number of minutes for which the appliances are used per week are presented in Table I.11

Table I.11 Number of minutes for which the appliances are used per week - Percentage of responses.

Appliance	5	10	15	20	30	40	50	60	90	120
Vacuum Cleaner		20	3.3	23.3	20		3.3	16.7	6.7	3.3
Hair Dryer	42.3	11.5	11.5	11.5	7.7	11.5				3.8
Liquidiser	87.5	12.5								
Food Mixer	50	31.8	4.5		9.1			4.5		

The amount of time (in minutes) the appliances are used depends very much on the appliance, and also on how many times it is used per week. Most appliances were used for no more than 20 minutes per week - except the vacuum cleaner, which was also used for 60, 90 or 120 minutes per week.

I.3.5 Do you consider the appliances to be noisy?

Table I.12 presents the noisiness ratings for these four appliances used in the home (where 1 = Very quiet and 7 = Extremely noisy).

Table I.12 Noisiness ratings for the appliances - Percentage of responses to each category.

Appliance	1	2	3	4	5	6	7
Vacuum Cleaner	10	20	6.7	10	20	16.7	16.7
Hair Dryer	25.9	11.1	11.1	14.8	18.5	3.7	14.8
Liquidiser	18.8			6.3	25	31.3	18.8
Food Mixer	18.2	9.1	4.5	13.6	13.6	22.7	18.2

Of these four appliances, over half subjects rated their noise level 4 - 7 (moderately to extremely noisy). Only a small sample considered the noise level of these appliances to be very quiet or quiet.

I.3.6 Do you believe manufactures are concerned about noise from their appliances?

Table I.13 presents the percentage of responses to the regarding manufacturers concern about the noise of domestic appliances.

Table I.13 Manufacturers concern about the noise from their domestic appliances - Percentage of responses.

Response	% of total N=32
Yes	37.5
No	34.4
Not Sure	28.1

Subjects were divided over this question, with almost equal numbers replying ' yes' and 'no'.

I.4 Questions 3a to 3c

I.4.1 How much time per week do you spend inside your home?

Table I.14 presents the amount of time (in hours) that subjects spent inside their home.

Table I.14 The amount of time per week (in hours) spent inside the home - Percentage of responses.

Hours	% of responses
51 - 60	6.2
61 - 70	12.5
71 - 80	12.5
81 - 90	9.4
91 - 100	34.4
101 - 110	0.0
111 - 120	18.8
121 - 130	3.1
131 - 140	0.0
141 - 150	3.1

The maximum amount of time spent inside the home/week was between 141 and 150 hours. During this time people were exposed to noise in the domestic environment. Over half the subjects spent at least 91 hours in the domestic environment.

I.4.2 How do you spend your time inside your home?

In Table I.15 are presented the ways in which subjects spend their time when in the home.

Table I.15 Activities subjects are involved in whilst inside their home - Percentage of responses.

Activity	% of total N= 32
Watching TV	75
Playing musical instruments	12.5
Reading	59.4
Studying	21.9
DIY	15.6
Cleaning	31.3
Entertaining	9.4
Sleeping	65.6
Eating	56.3
Listening to music	46.9
Talking	12.5
Knitting	6.3

Of these activities, the ones most likely to affect hearing are DIY, playing instruments and listening to music (depending on the level at which it is played). Few subjects participated in DIY and playing instruments. Nearly half of the subjects spent some time listening to music.

I.4.3 What are your hobbies?

Table I.16 presents the hobbies that subjects quoted. Of the hobbies listed, the

Table I.16 Subjects' hobbies - Percentage of responses.

Hobby	% of responses
Reading	56.3
Theatre	6.3
Music	18.8
Playing musical instruments	18.8
Athletics	59.4
Gardening	15.6
DIY	15.6
Travel	6.3
Photography	12.5
Walking	12.5
Socialising	6.3
Cookery	3.1

noisy ones are DIY, and playing instruments. Again the majority of subjects did not participate in such hobbies.

I.5 Questions 4a to 4f

I.5.1 Are you ever disturbed by noise from your neighbours?

Table I.17 presents the responses to this question.

Table I.17 Disturbance by noise from neighbours - Percentage of responses.

Response	% of total N = 32
Yes	62.5
No	37.5

It is interesting to note that more subjects were disturbed by the noise from neighbours than were not disturbed.

I.5.2 If 'Yes', what sort of noise?

Table I.18 presents the source of neighbour's noise disturbing subjects.

Table I.18 Neighbour's noises disturbing subjects - Percentage of responses.

Noise	% of responses
Children	30
TV	15
Music	40
Noise from musical instruments	15
Domestic appliances	30
Voices	30
Door bell	10

The link between dwelling type and disturbance by neighbour's noise

Table I.19 presents the numbers of subjects disturbed by neighbour's noise when compared with the dwelling type in which subjects live.

Table I.19 Disturbance be neighbour's noise and dwelling type - Percentage of responses.

House type	Disturbed	Not Disturbed
Flat	6.3	3.1
Terrace	34.4	9.4
Semi-detached	12.5	12.5
Detached	9.4	12.5

When comparing dwelling type with reported disturbance by neighbours, it can be seen that the largest proportions of subjects disturbed lived in terraced properties, where presumably subjects are potentially disturbed by neighbours on either side if the sound insulation is poor. For the subjects occupying detached dwellings, the noise level causing the disturbance is more than likely to be from external sources, such as voices when people are leaving, out-door parties and so on.

I.5.3 Sensitivity Questions

The next group of questions related to the sensitivity of subjects. They are a series of questions used extensively in noise surveys, and first devised by McKennell [55]

In general, does noise ever bother, annoy or disturb you in any way?

The responses to this question are presented in Table I.20.

Table I.20 Percentage of responses to each category.

Response	% of total N = 32
Very Often	9.4
Fairly often	28.1
Occasionally	46.9
Hardly ever	15.6

Over half the subjects replied that noise bothered, annoyed or disturbed them occasionally or hardly ever. For the remaining 31.5% of subjects they were disturbed either fairly or very often.

On the whole, would you say there is too much or too little fuss made about noise nowadays?

The responses to this question are presented in Table I.21.

Table I.21 Percentage of responses to each category.

Response	% of total N = 32
Too much fuss	0
About right	46.9
Too little fuss	40.6
Don't know	12.5

None of the subjects felt there was 'too much fuss' made about noise. Subjects were equally divided in the responses 'about right' and 'too little fuss', with a small proportion unable to reply.

Would you say you are more or less sensitive than other people to noise?

The responses to this question are presented in Table I.22.

Table I.22 Percentage of responses to each category.

Response	% of total N = 32
More sensitive	25.0
Less sensitive	15.6
The same	59.4
Don't know	0

Over half the subjects felt they were not more or less sensitive than other people to noise - just the same. However, a quarter of the subjects felt they were more sensitive, and about one sixth thought they were less sensitive.

How far would you agree or disagree with the people who say 'noise is one of the biggest nuisances of modern times'?

The responses to this question are presented in Table I.23.

Table I.23 Percentage of responses to each category.

Response	% of total N = 32
Strongly agree	12.5
Agree	40.6
Disagree	40.6
Disagree strongly	3.1
Don't know	3.1

Again, subjects were equally divided over whether they agreed or disagreed with the statement. Only 12% strongly agreed while just 3% disagreed strongly, and 3% did not know.

Could you sum up you opinion by saying whether you find noise....

The percentage of responses to this question are presented in Table I.24.

Table I.24 Percentage of responses to each category.

Response	% of total N = 32
Very disturbing	15.6
Disturbing	21.9
A little disturbing	62.5
Not at all disturbing	0

Over half the subjects completing the questionnaire considered noise to be 'a little disturbing'. Just over 21% found it 'disturbing' and 15% found noise very disturbing.

In each of these questions, between 10 and 40% of subjects could be categorized as quite sensitive to noise in that they completed the most noise sensitive responses.

I.5.4 Scoring Sensitivity

Using a scaling technique similar to that used in Chapter 8, section 8.7, scores for sensitivity were assigned to the response categories of each question, and the scores were summed to determine the subjects' overall sensitivity. The following scores were used:

In general, does noise ever bother, annoy or disturb you in any way?

RESPONSE	SCORE
Very often	4
Fairly often	3
Occasionally	2
Hardly Ever	1
Don't know	0

On the whole, would you say there is too much or too little fuss made about
noise nowadays?

RESPONSE	SCORE
Too much fuss	1
About right	2
Too little	3
Dont' know	0

Would you say you were more or less sensitive than other people to noise?

RESPONSE	SCORE
More sensitive	3
Less sensitive	1
The same	2
Don't know	0

How far would you agree or disagree with the people who say 'noise is one of the
biggest nuisances of modern time?

RESPONSE	SCORE
Strongly agree	4
Agree	3
Disagree	2
Disagree strongly	1
Dont' know	0

Could you sum up your opinion by saying whether you find noise.....

RESPONSE	SCORE
Very disturbing	4
Disturbing	3
A little disturbing	2
Not at all disturbing	1

The maximum score for sensitivity was 18 and the minimum score 1. The scores were then summed and categorised into the following categories - (the column headed % represents the percentage of scores in each category):

CATEGORY	SCORE	%
Not sensitive	0 - 4	0
Fairly sensitive	5 - 9	22
Sensitive	10 - 14	53
Very sensitive	15 - 18	25

The average score was 11.65, which falls into the 'sensitive' category. Using the summed sensitivity scores it was possible to determine who were the sensitive subjects (ie. into which classifications they belonged).

Noise sensitivity and Sex of respondent

Table I.25 presents the percentage of male and female subjects in each category of noise sensitivity.

Table I.25 Percentage of male and female subjects in each category of noise sensitivity.

Category	Male	Female
Not sensitive		
Fairly sensitive	18	27
Sensitive	71	33
Very sensitive	11	40

From this table the following observations can be made:

1. Almost equal numbers of male and female subjects fell into the 'fairly insensitive' category.
2. For the remainder of the male subjects, their sensitivity scores put them largely in the category 'sensitive'.
3. However, for the remaining female subjects, their scores divided them equally into 'sensitive' and 'very sensitive'.
4. More female subjects were 'very sensitive' compared to male subjects. However, more males were 'sensitive' compared to female subjects.

Noise sensitivity and age of respondent

Table I.26 presents the percentage of subjects in each age group according to their noise sensitivity.

From this table the following points can be made:

Table I.26 Percentage of subjects classified by age in each category of noise sensitivity.

Age group	Not sensitive	Fairly sensitive	Sensitive	Very Sensitive
1921 - 1930				100
1931 - 1940			100	
1941 - 1950			75	25
1951 - 1960		11	78	11
1961 - 1970		35	41	24

1. Of the 'fairly insensitive' subjects, the majority were in the age group 1961 - 1970.
2. The 'sensitive' and 'very sensitive' subjects were from a mixture of age groups.

Noise sensitivity and occupation

Due to the small numbers of respondents in each occupational category, it was not possible to analyse the noise sensitivity data in term of the occupations of the respondents.

I.6 Classification questions

A number of classificatory questions were included in the questionnaire. The results are presented in the following subsections.

I.6.1 Year Born

Table I.27 presents a classification of subjects into the year they were born.

Table I.27 Classification of subjects into year born - Percentage of responses.

Year	% of responses
1921 - 1930	3.1
1931 - 1940	3.1
1941 - 1950	12.5
1951 - 1960	28.2
1961 - 1970	53.1

I.6.2 Sex of respondents

Table I.28 presents the sex of respondents.

Table I.28 Sex of respondents - Percentage of each.

Sex	% of responses
Male	43.8
Female	56.3

I.6.3 Occupation of respondents

The various occupations of the respondents are presented in Table I.29.

Table I.29 Occupation of respondents - Percentage in each category.

Occupation	% of responses
Researcher	43.8
Lecturer	6.3
Technician	25.0
Secretary	15.6
Course manager	3.1
Editor	3.1
Designer	3.1

When asked if the occupation was part or full time the responses were as follows:

	%
Full time	97
Part time	3

I.6.4 Age the respondents finished full time education

Table I.30 presents the classifications for the age when respondents finished full time education.

Table I.30 Classifications for the age when the respondents finished full time education - Percentage of responses in each category.

Age classification	% of responses
16 - 18	28.1
After college or university	25.0
After post graduate work	34.4
Still in full time education	12.5

I.6.5 Type of dwelling occupied

Table I.31 presents the dwelling types occupied by respondents;

Table I.31 Dwelling type occupied by respondents - Percentage in each type.

Dwelling Type	% of responses
Flat	9.4
Terraced	43.8
Semi-detached	25.0
Detached	21.9

Appendix J

Questionnaire 2

QUESTIONNAIRE 2

DATE: ____________________ SESSION NUMBER: ______________

NAME: ____

Thank you very much for your co-operation in this test. I would be grateful if you could supply me with the following information:

For the appliances used in this test, could you answer the following questions:

(A) Do you consider the appliance to be:

Please tick the appropriate box

APPLIANCE NUMBER

	1	2	3	4	5	6
Not very useful						
A little useful						
Moderately useful						
Extremely useful						

Please tick the appropriate box

(B) Do you consider the appliance to be

Please tick the appropriate box

APPLIANCE NUMBER

	1	2	3	4	5	6
(i) Not annoying at all						
(ii) A little annoying						
(iii) Moderately annoying						
(iv) Extremely annoying						

If you have ticked (ii), (iii) or (iv), please briefly give your reasons for your annoyance:

Appliance 1: ______________________________

____

Appliance 2: ______________________________

____

Appliance 3: ______________________________

____

Appliance 4: ______________________________

____

Appliance 5: ______________________________

____

Appliance 6: ______________________________

____

(C) Would you consider the appliance used in this test to be acceptable, from the point of view of noise, for use in your home?

Appliance 1: YES ☐ NO ☐

Appliance 2: YES ☐ NO ☐

Appliance 3: YES ☐ NO ☐

Appliance 4: YES ☐ NO ☐

Appliance 5: YES ☐ NO ☐

Appliance 6: YES ☐ NO ☐

Please tick appropriate box

Appendix K

General Instructions

The instructions used to aid subjects in the experiments were as follows.

K.1 General Instructions

Thank you for volunteering to participate in this study, the purpose of which is to investigate subjective reactions to a selection of noises normally experienced in the home due to the use of electrical appliances. It is hoped that the data gathered will contribute towards the development of an effective method for the sound labelling of domestic appliances.

In this test you will listen to six (or four) different appliances, each of which you will be asked to rate according to how noisy you judge it to be. When making your response, imagine you are listening to the appliances in your own home. Don't worry about the reaction of your neighbour - it is your opinion that is important.

K.2 Instructions to the User

1. Please do not talk during the session.
2. I will indicate when you should switch the appliances on and off.
3. After using each appliance, please complete the rating sheet by judging how noisy you consider the appliance to be, then move on to the next appliance.
4. When using the appliances in the kitchen, please lie the sound level meter where indicated.
5. When using the appliances in the lounge, please hold the sound level meter at shoulder height. Please do not touch any of the buttons on the sound level meter when holding the meter or when moving it from one location to another.
6. When using the vacuum cleaner, please use it in the area where it has been placed, and use it as you would normally, cleaning the carpet in front of you.
7. When using the hair dryer, please use it on speed 1, and use it as you would normally if you were drying your hair.

8. After using 4 appliances, please pass the meter and your rating sheet to me and sit down in the lounge.

Appendix L

Latin Square Design for each experiment

L.1 Experiments 1, 2, and 3

These experiments aimed to investigate hypotheses 1, 2, 3, and 4. The same Latin square design was adopted for each experiment.

SESSION A				SESSION B			
VC	FP	HD	LIQ	LIQ	HD	FP	VC
FP	LIQ	VC	HD	HD	VC	LIQ	FP
LIQ	HD	FP	VC	VC	FP	HD	LIQ
HD	VC	LIQ	FP	FP	LIQ	VC	HD

```
where VC  = Hoover 119 Vacuum Cleaner
      FP  = Braun MC-1 Food Processor
      LIQ = Moulinex 530 Liquidiser
      HD  = Clairol 1200 Hair Dryer
```

L.2 Experiment 4

This experiment aimed to investigate hypotheses 5 - 11. The Latin square design was as follows:

SESSION A						SESSION B					
HD1	FM1	FM2	HD2	HD4	HD3	HD3	HD4	HD2	FM2	FM1	HD1
FM1	HD2	HD1	HD3	FM2	HD4	HD4	FM2	HD3	HD1	HD2	FM1
HD2	HD3	FM1	HD4	HD1	FM2	FM2	HD1	HD4	FM1	HD3	HD2
HD3	HD4	HD2	FM2	FM1	HD1	HD1	FM1	FM2	HD2	HD4	HD3
HD4	FM2	HD3	HD1	HD2	FM1	FM1	HD2	HD1	HD3	FM2	HD4
FM2	HD1	HD4	FM1	HD3	HD2	HD2	HD3	FM1	HD4	HD1	FM2

where HD1 = Boots MD2 Hair Dryer - Speed 1
FM1 = Philips HR1907 Food Mixer - Speed 1
HD2 = Moulinex 722 Beauty Styler Hair Dryer - Speed 1
HD3 = Ronson Hotshot Hair Dryer - Speed 1
HD4 = Braun 1500 Compact Hair Dryer - Speed 2
FM2 = Kenwood Mini A345Food Mixer - Speed 2

L.3 Experiment 5

This experiment aimed to investigate hypotheses 5 - 11. The Latin square design was as follows:

SESSION A						SESSION B					
VC1	HD1	HD3	FM1	HD2	LIQ1	LIQ1	HD2	FM1	HD3	HD1	VC1
HD1	FM1	VC1	LIQ1	HD3	HD2	HD2	HD3	LIQ1	VC1	FM1	HD1
FM1	LIQ1	HD1	HD2	VC1	HD3	HD3	VC1	HD2	HD1	LIQ1	FM1
LIQ1	HD2	FM1	HD3	HD1	VC1	VC1	HD1	HD3	FM1	HD2	LIQ1
HD2	HD3	LIQ1	VC1	FM1	HD1	HD1	FM1	VC1	LIQ1	HD3	HD2
HD3	VC1	HD2	HD1	LIQ1	FM1	FM1	LIQ1	HD1	HD2	VC1	HD3

where VC1 = Electrolux 520S Vacuum Cleaner
HD1 = Braun 1200 Supercompact Hair Drier - Speed 1
FM1 = Philips HM3060 Food Mixer - Speed 1
LIQ1 = Philips TX2000 Liquidiser - Speed 1
HD2 = Moulinex 722 Beauty Styler Hair Dryer - Speed 2
HD3 = Boots MD2 Hair Dryer - Speed 2

L.4 Experiment 6

This experiment aimed to investigate hypotheses 5 - 11. The Latin square design was as follows:

SESSION A

VC1	FP1	VC4	VC2	HD1	VC3
FP1	VC2	VC1	VC3	VC4	HD1
VC2	VC3	FP1	HD1	VC1	VC4
VC3	HD1	VC2	VC4	FP1	VC1
HD1	VC4	VC3	VC1	VC2	FP1
VC4	VC1	HD1	FP1	VC3	VC2

SESSION B

VC3	HD1	VC2	VC4	FP1	VC1
HD1	VC4	VC3	VC1	VC2	FP1
VC4	VC1	HD1	FP1	VC3	VC2
VC1	FP1	VC4	VC2	HD1	VC3
FP1	VC2	VC1	VC3	VC4	HD1
VC2	VC3	FP1	HD1	VC1	VC4

```
where VC1 = Electrolux ZA 65 Vacuum Cleaner
      FP1 = Prestige L2001 Food Processor
      VC2 = Electrolux 350E Vacuum Cleaner
      VC3 = Kerstar C606 Supreme Vacuum Cleaner
      HD1 = Clairol 1200 Hair Dryer - Speed 1
      VC4 = Electrolux 345 Vacuum Cleaner
```

L.5 Experiment 7

This experiment aimed to investigate hypotheses 5 - 11. The Latin square design was as follows:

SESSION A

FM1	VC1	HD3	LIQ1	HD2	HD1
VC1	LIQ1	FM1	HD1	HD3	HD2
LIQ1	HD1	VC1	HD2	FM1	HD3
HD1	HD2	LIQ1	HD3	VC1	FM1
HD2	HD3	HD1	FM1	LIQ1	VC1
HD3	FM1	HD2	VC1	HD1	LIQ1

SESSION B

HD1	HD2	LIQ1	HD3	VC1	FM1
HD2	HD3	HD1	FM1	LIQ1	VC1
HD3	FM1	HD2	VC1	HD1	LIQ1
FM1	VC1	HD3	LIQ1	HD2	HD1
VC1	LIQ1	FM1	HD1	HD3	HD2
LIQ1	HD1	VC1	HD2	FM1	HD3

```
where FM1  = Kenwood Chef A901 Food Mixer - Speed 4
      VC1  = Electrolux 350E Vacuum Cleaner - Superboost
      LIQ1 = Moulinex 530 Liquidiser
      HD1  = Braun 1200 Supercompact Hair Dryer - Speed 2
      HD2  = Ronson Hotshot Hair Dryer - Speed 2
      HD3  = Braun 1500 Compact Hair Dryer - Speed 3
```

L.6 Experiment 8

This experiment aimed to investigate hypotheses 5 - 11. The Latin square design was as follows:

SESSION A						SESSION B					
LIQ1	VC1	FP2	LIQ2	VC2	FP1	FP1	VC2	LIQ2	FP2	VC1	LIQ1
VC1	LIQ2	LIQ1	FP1	FP2	VC2	VC2	FP2	FP1	LIQ1	LIQ2	VC1
LIQ2	FP1	VC1	VC2	LIQ1	FP2	FP2	LIQ1	VC2	VC1	FP1	LIQ2
FP1	VC2	LIQ2	FP2	VC1	LIQ1	LIQ1	VC1	FP2	LIQ2	VC2	FP1
VC2	FP2	FP1	LIQ1	LIQ2	VC1	VC1	LIQ2	LIQ1	FP1	FP2	VC2
FP2	LIQ1	VC2	VC1	FP1	LIQ2	LIQ2	FP1	VC1	VC2	LIQ1	FP2

where LIQ1 = Kenwood Chef A901 Food Mixer with Liquidiser attachment
VC1 = Hoover 119 Vacuum Cleaner
LIQ2 = Moulinex 241.1 Liquidiser
FP1 = Braun MC-11 Food Processor
VC2 = Hoover U2002 Vacuum Cleaner
FP2 = Robot Chef RC3Food Processor

Appendix M

Distribution of average scores from throwing various numbers of dice

Figure M.1 shows how, with increased numbers of dice throws, the distribution of average scores approximates to the normal distribution. [116]

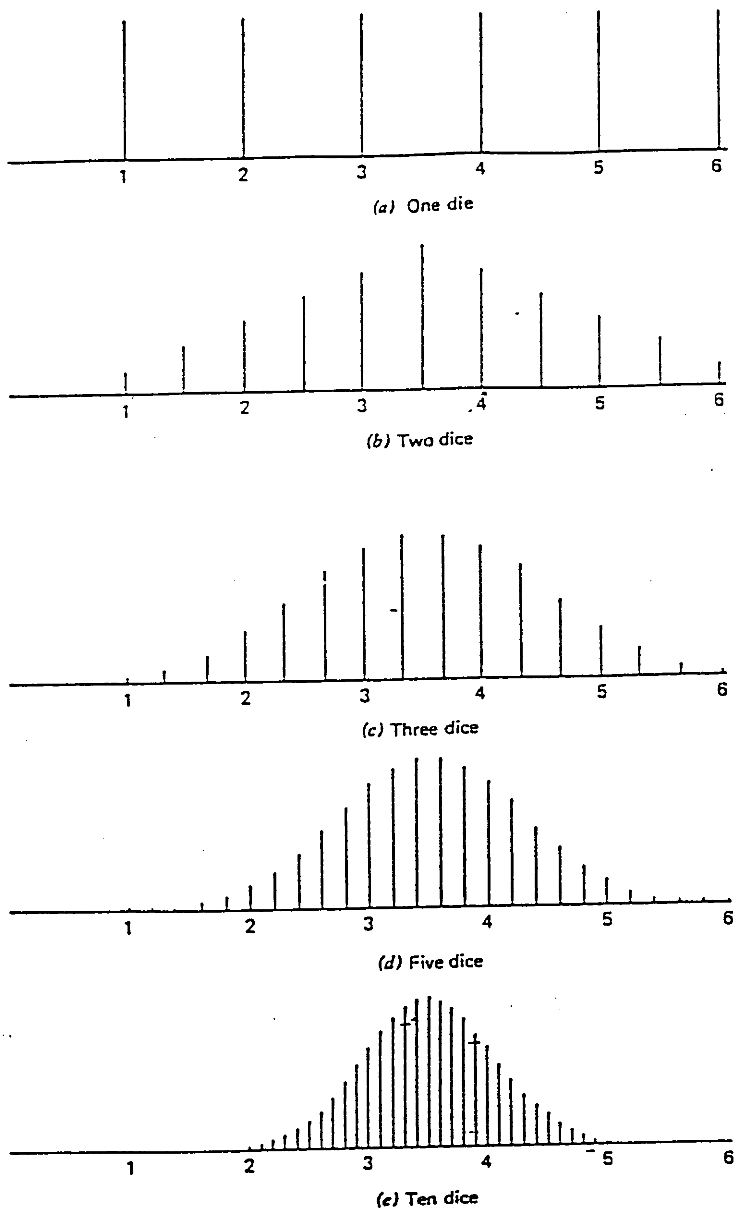


Figure M.1 Distribution of average scores to demonstrate approximations to the normal distribution.

Appendix N

Variance Ratio Table

Table (N.1) shows the critical values for variance ratio used in testing for Homogeneity of Variance.

Figure N.1 Percentage points of the ratio s^2 max/s^2 min.

Upper 5 % points

ν \ k	2	3	4	5	6	7	8	9	10	11	12
2	39·0	87·5	142	202	266	333	403	475	550	626	704
3	15·4	27·8	39·2	50·7	62·0	72·9	83·5	93·9	104	114	124
4	9·60	15·5	20·6	25·2	29·5	33·6	37·5	41·1	44·6	48·0	51·4
5	7·15	10·8	13·7	16·3	18·7	20·8	22·9	24·7	26·5	28·2	29·9
6	5·82	8·38	10·4	12·1	13·7	15·0	16·3	17·5	18·6	19·7	20·7
7	4·99	6·94	8·44	9·70	10·8	11·8	12·7	13·5	14·3	15·1	15·8
8	4·43	6·00	7·18	8·12	9·03	9·78	10·5	11·1	11·7	12·2	12·7
9	4·03	5·34	6·31	7·11	7·80	8·41	8·95	9·45	9·91	10·3	10·7
10	3·72	4·85	5·67	6·34	6·92	7·42	7·87	8·28	8·66	9·01	9·34
12	3·28	4·16	4·79	5·30	5·72	6·09	6·42	6·72	7·00	7·25	7·48
15	2·86	3·54	4·01	4·37	4·68	4·95	5·19	5·40	5·59	5·77	5·93
20	2·46	2·95	3·29	3·54	3·76	3·94	4·10	4·24	4·37	4·49	4·59
30	2·07	2·40	2·61	2·78	2·91	3·02	3·12	3·21	3·29	3·36	3·39
60	1·67	1·85	1·96	2·04	2·11	2·17	2·22	2·26	2·30	2·33	2·36
∞	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00

Appendix O

Significance of the Variance Ratios

In order to test for homogeneity of variance, one method is to identify constant variance across the treatment groups. This was performed by examining the ratio between maximum and minimum variance of the residual values, and identifying cases where any ratio was significant. Tables O.1 O.2 O.3 O.4 O.5 O.6 O.7 O.8 present the product of the ratio and the value which, if exceeded, identifies cases where there is no constant variance across treatment groups.

Table O.1 Significance of the Variance Ratio - Hypotheses 1 and 2.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	1.760	≥1.96
Order of Presentation	1.379	≥1.96
Session	1.280	≥1.38

Table O.2 Significance of the Variance Ratio - Hypothesis 3.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	1.701	≥1.96
Order of Presentation	1.316	≥1.96
User/Listener condition	1.150	≥1.38
Session	1.372	≥1.38
Appliance x Listener Interaction	2.687	≥3.12

Table O.3 Significance of the Variance Ratio - Hypothesis 4.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	1.681	$\geq$1.96
Order of Presentation	1.257	$\geq$1.96
Session	1.372	$\geq$1.38
Order x Session Interaction	2.602	$\geq$3.12

Table O.4 Significance of the Variance Ratio - Hypothesis 5 - Group 1 Appliances.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	1.603	$\geq$2.91
Order of Presentation	1.548	$\geq$2.91
Session	1.118	$\geq$1.38
Order x Session Interaction	2.340	$\geq$4.59

Table O.5 Significance of the Variance Ratio - Hypothesis 5 - Group 2 Appliances.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	2.856	$\geq$2.91
Order of Presentation	1.906	$\geq$2.91
Session	1.022	$\geq$1.38
Order x Session Interaction	2.020	$\geq$4.59

Table O.6 Significance of the Variance Ratio - Hypothesis 5 - Group 3 Appliances.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	2.299	≥2.91
Order of Presentation	1.831	≥2.91
Session	1.087	≥1.38
Order x Session Interaction	3.397	≥4.59

Table O.7 Significance of the Variance Ratio - Hypothesis 5 - Group 4 Appliances.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	2.684	≥2.91
Order of Presentation	1.377	≥2.91
Session	1.220	≥1.38
Order x Session Interaction	2.015	≥4.59

Table O.8 Significance of the Variance Ratio - Hypothesis 5 - Group 5 Appliances.

Effect	s^2 max/s^2 min	Significance value (p<.05)
Appliance	2.707	≥2.91
Order of Presentation	2.067	≥2.91
Session	1.064	≥1.38
Order x Session Interaction	2.731	≥4.59

Appendix P

Statistical summaries of the ratings for each experiment

This appendix presents the results of the statistical summary of the ratings for each Hypothesis (See Tables P.1 P.2 P.3 P.4 P.5 P.6 P.7 P.8 P.9 P.10).

Table P.1 Statistical summaries of the ratings for Hypothesis 1.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Vacuum Cleaner	5.484	6.0	1.069	3.0	7.0	5.0	6.0
Food Processor	5.406	5.0	0.971	3.0	7.0	5.0	6.0
Liquidiser	4.750	5.9	1.039	2.0	7.0	4.0	5.0
Hair Dryer	3.687	4.0	0.871	2.0	6.0	3.0	4.0

Table P.2 Statistical summaries of the User ratings for Hypothesis 3.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Vacuum Cleaner	5.031	5.0	0.967	3.0	7.0	4.25	6.0
Food Processor	6.469	7.0	0.718	4.0	7.0	6.0	7.0
Liquidiser	4.844	5.0	0.954	3.0	7.0	4.0	5.75
Hair Dryer	3.75	4.0	1.078	2.0	5.0	3.0	5.0

Table P.3 Statistical summaries of the Listener ratings for Hypothesis 3.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Vacuum Cleaner	5.531	6.0	0.879	4.0	7.0	5.0	6.0
Food Processor	5.750	6.0	0.916	3.0	7.0	5.0	6.0
Liquidiser	4.594	4.0	1.103	3.0	7.0	4.0	5.75
Hair Dryer	3.625	3.5	1.185	2.0	6.0	3.0	4.75

Table P.4 Statistical summaries of the ratings for Hypothesis 4 - 15 seconds.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Vacuum Cleaner	5.219	5.0	1.07	3.0	7.0	4.25	6.0
Food Processor	5.656	5.0	0.937	4.0	7.0	5.0	6.75
Liquidiser	4.844	5.0	0.987	3.0	7.0	4.0	5.0
Hair Dryer	3.687	4.0	0.965	2.0	6.0	3.0	4.0

Table P.5 Statistical summaries of the ratings for Hypothesis 4 - 30 seconds.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Vacuum Cleaner	5.531	6.0	0.761	4.0	7.0	5.0	6.0
Food Processor	5.875	6.0	0.871	4.0	7.0	5.25	6.0
Liquidiser	5.000	5.0	0.984	3.0	7.0	4.0	6.0
Hair Dryer	3.813	4.0	0.821	2.0	5.0	3.0	4.0

Table P.6 Statistical summaries of the ratings for Hypothesis 5 - Group 1 Appliances.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Boots MD2 HD - Sp. 1	3.229	3.0	1.153	1.0	6.0	2.0	4.0
Philips HR1907 FM - Sp. 1	4.646	4.0	1.041	2.0	7.0	4.0	5.75
Moulinex 722 HD - Sp. 1	3.813	3.5	1.024	2.0	6.0	3.0	5.0
Ronson Hotshot HD - Sp. 1	4.021	4.0	0.887	2.0	6.0	3.0	5.0
Braun 1500 Compact HD - Sp. 1	3.958	4.0	1.129	2.0	7.0	3.0	5.0
Kenwood Mini A345 FM - Sp. 2	4.250	4.0	0.957	2.0	6.0	4.0	5.0

Table P.7 Statistical summaries of the ratings for Hypothesis 5 - Group 2 Appliances.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Electrolux 520S VC	4.125	4.0	0.866	3.0	6.0	4.0	5.0
Braun 1200 Supercompact HD - Sp. 1	3.563	3.5	1.050	2.0	6.0	3.0	4.0
Philips HM3060 FM - Sp. 1	4.542	4.5	1.091	3.0	7.0	4.0	5.0
Philips TX2000 LIQ - Sp. 1	5.375	5.0	0.866	3.0	7.0	5.0	6.0
Moulinex 722 HD - Sp. 2	4.833	5.0	0.996	3.0	7.0	4.0	6.0
Boot MD2 HD - Sp. 2	3.979	4.0	1.329	2.0	6.0	3.0	5.0

Table P.8 Statistical summaries of the ratings for Hypothesis 5 - Group 3 Appliances.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Electrolux ZA65 VC	3.667	4.0	1.117	1.0	6.0	3.0	5.0
Prestige L2001 FP	4.271	4.0	1.106	2.0	7.0	4.0	5.0
Electrolux 350E VC	3.813	4.0	1.024	2.0	6.0	3.0	5.0
Kerstar C606 Supreme VC	4.125	4.0	0.981	2.0	6.0	3.25	5.0
Clairol 1200 HD - Sp. 1	3.896	4.0	1.016	2.0	6.0	3.0	5.0
Electrolux 345 VC	4.375	4.0	1.084	3.0	7.0	3.25	5.0

Table P.9 Statistical summaries of the ratings for Hypothesis 5 - Group 4 Appliances.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Kenwood Chef A901 FM	5.208	5.0	0.849	3.0	6.0	5.0	6.0
Electrolux 350E VC - Superboost	4.521	4.0	1.031	3.0	6.0	4.0	5.0
Moulinex 530 LIQ	5.062	5.0	0.932	3.0	6.0	4.0	6.0
Braun 1200 Supercompact HD - Sp. 2	4.438	4.0	1.009	2.0	6.0	4.0	5.0
Ronson Hotshot HD - Sp. 2	4.583	5.0	1.108	2.0	6.0	4.0	5.75
Braun 1500 Compact HD - Sp. 3	3.979	4.0	0.911	2.0	6.0	3.0	5.0

Table P.10 Statistical summaries of the ratings for Hypothesis 5 - Group 5 Appliances.

Appliance	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
Kenwood Chef A901 with LIQ	5.187	5.0	0.891	3.0	7.0	5.0	6.0
Hoover 119 VC	5.312	5.0	0.776	4.0	7.0	5.0	6.0
Moulinex 241.1 LIQ	5.271	5.0	0.644	4.0	6.0	5.0	6.0
Braun MC-1 FP	5.958	6.0	0.743	4.0	7.0	5.25	6.0
Hoover U2002 VC	6.187	6.0	0.704	5.0	7.0	6.0	7.0
Robot Chef RC3 FP	5.063	5.0	0.633	4.0	6.0	5.0	5.0

Appendix Q

Plots of noisiness ratings vs noise indices

The plots in this appendix represent the relationship between the various noise indices and mean noisiness rating for each appliance (where noisiness was assessed on a rating scale of 1 - 7: very quiet to extremely noisy). The mean noisiness rating was calculated for each appliance and then plotted against the various noise indices.

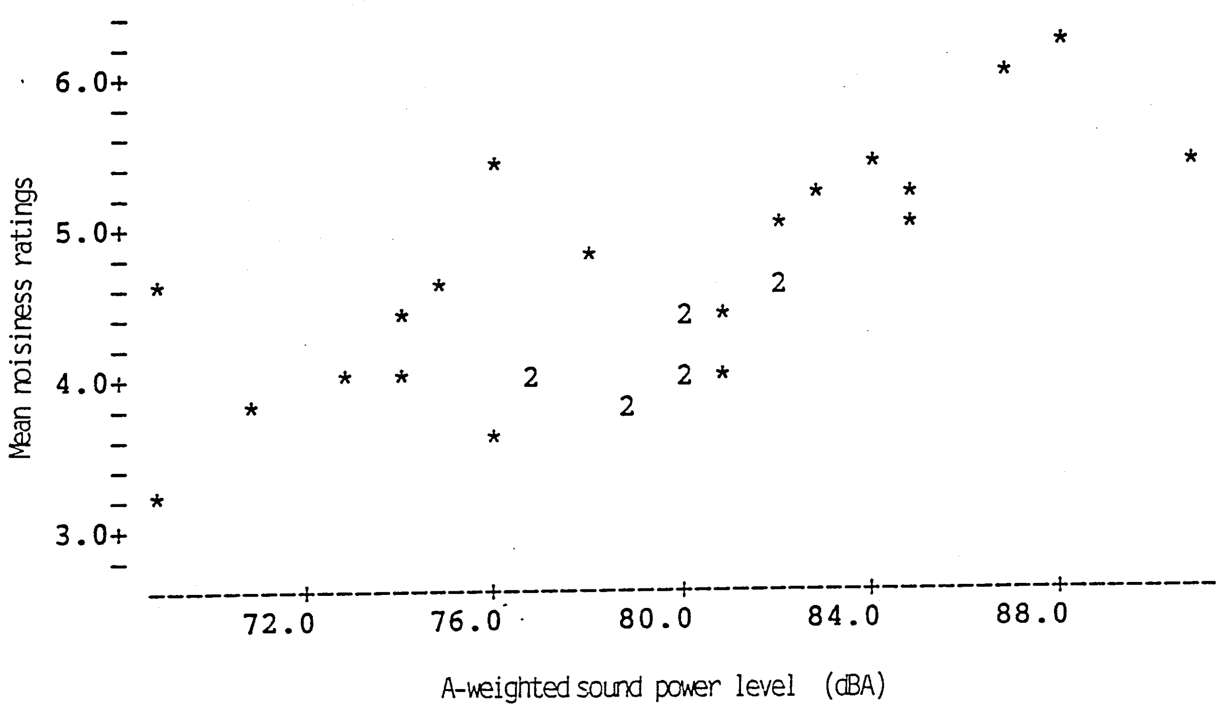


Figure Q.1 Mean noisiness ratings vs A-weighted sound power level

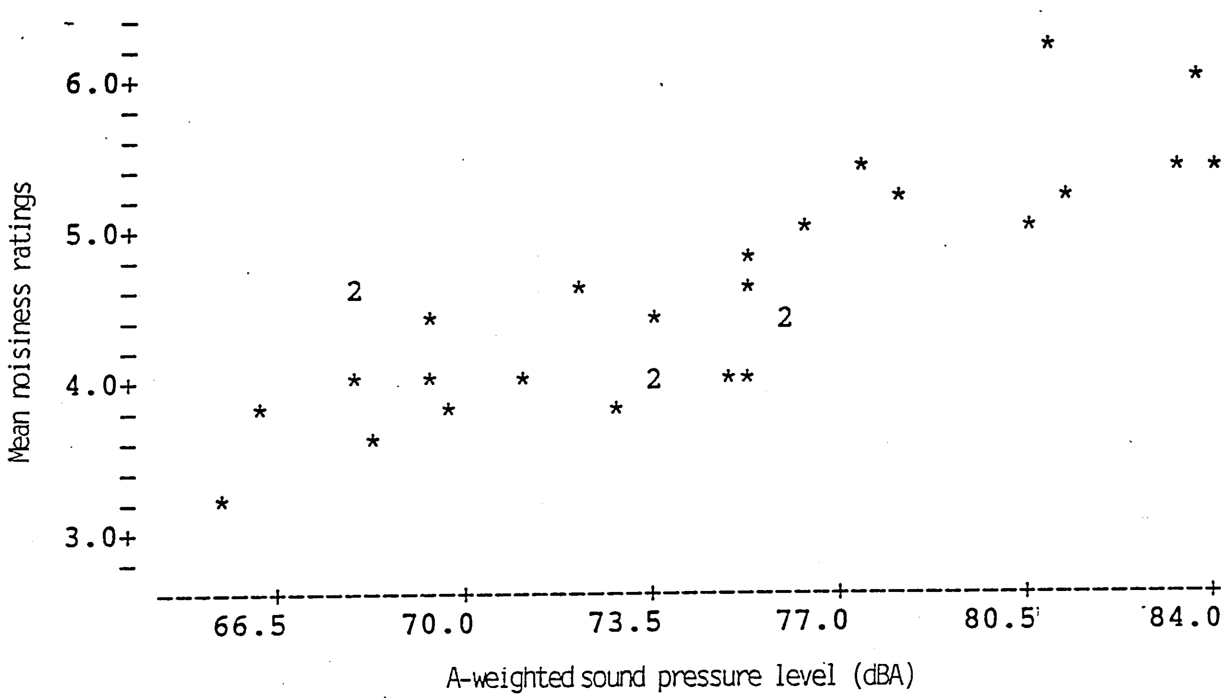


Figure Q.2 Mean noisiness ratings vs A-weighted sound pressure level

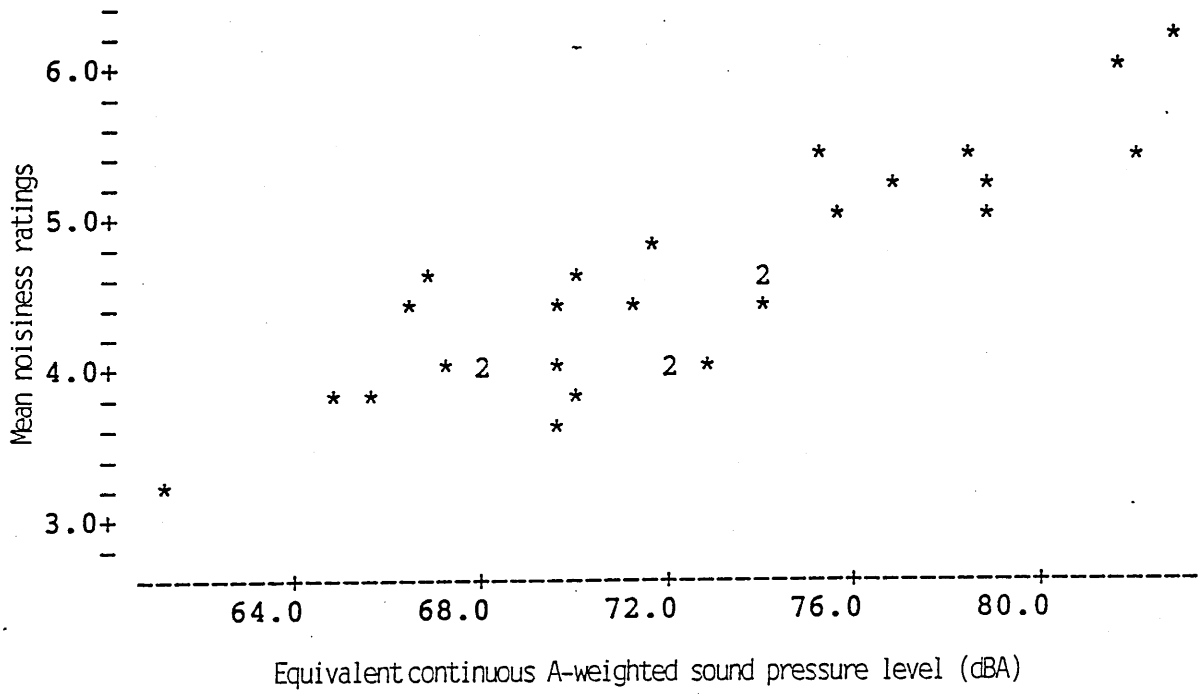


Figure Q.3 Mean noisiness ratings vs equivalent continuous A-weighted sound pressure level

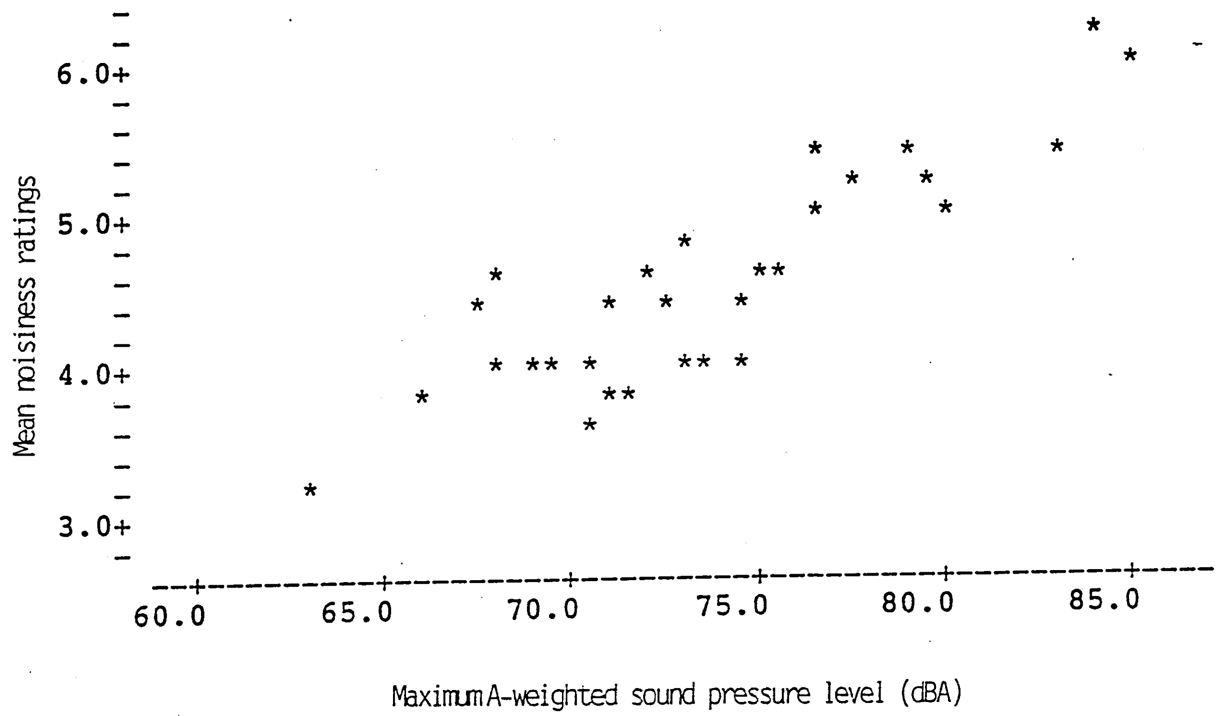


Figure Q.4 Mean noisiness ratings vs maximum A-weighted sound pressure level

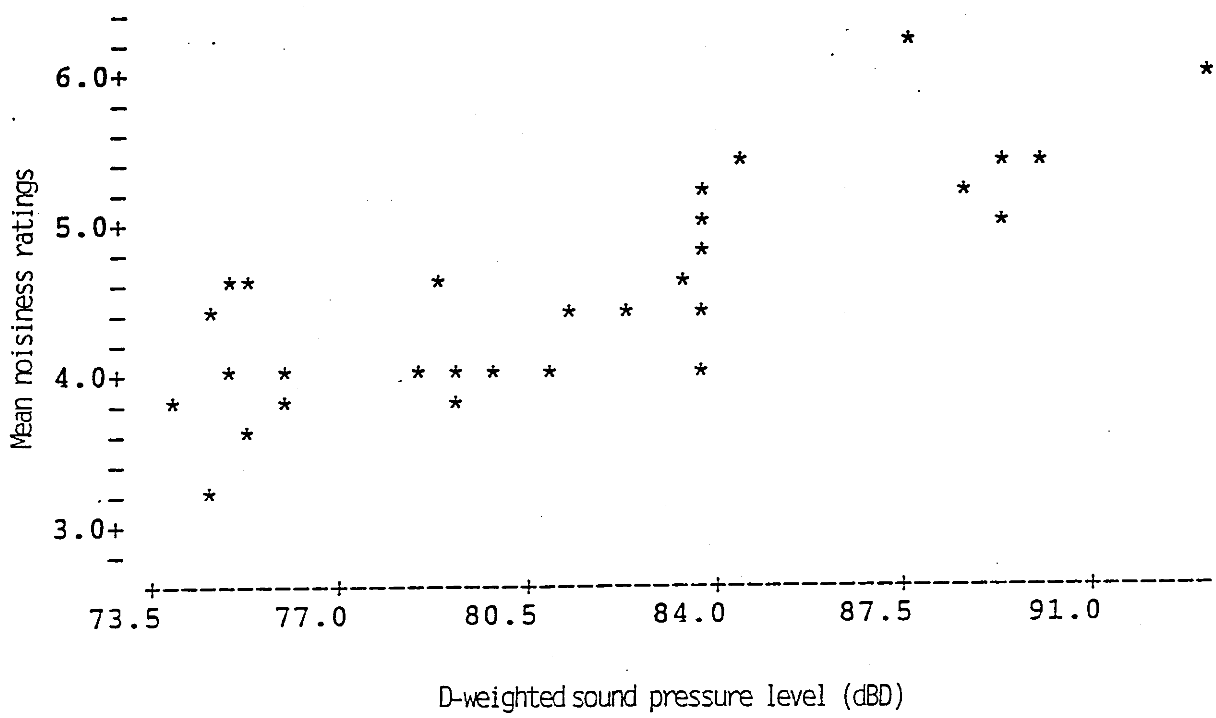


Figure Q.5 Mean noisiness ratings vs D-weighted sound pressure level

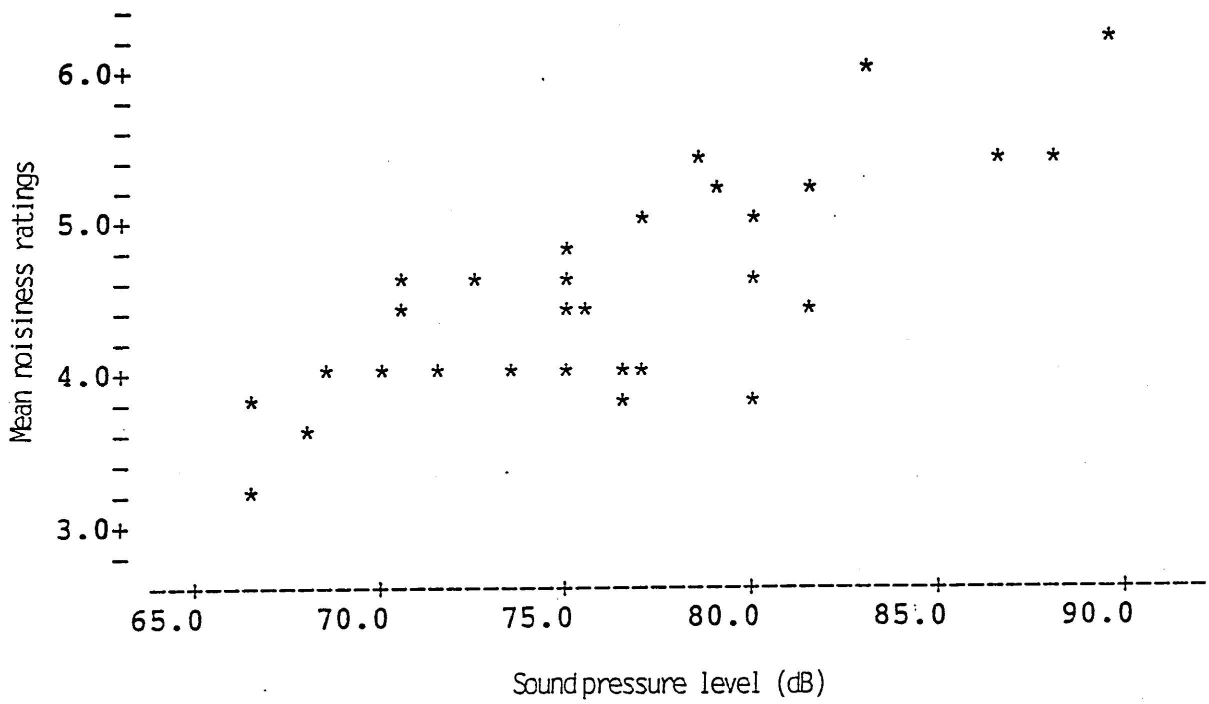


Figure Q.6 Mean noisiness ratings vs sound pressure level

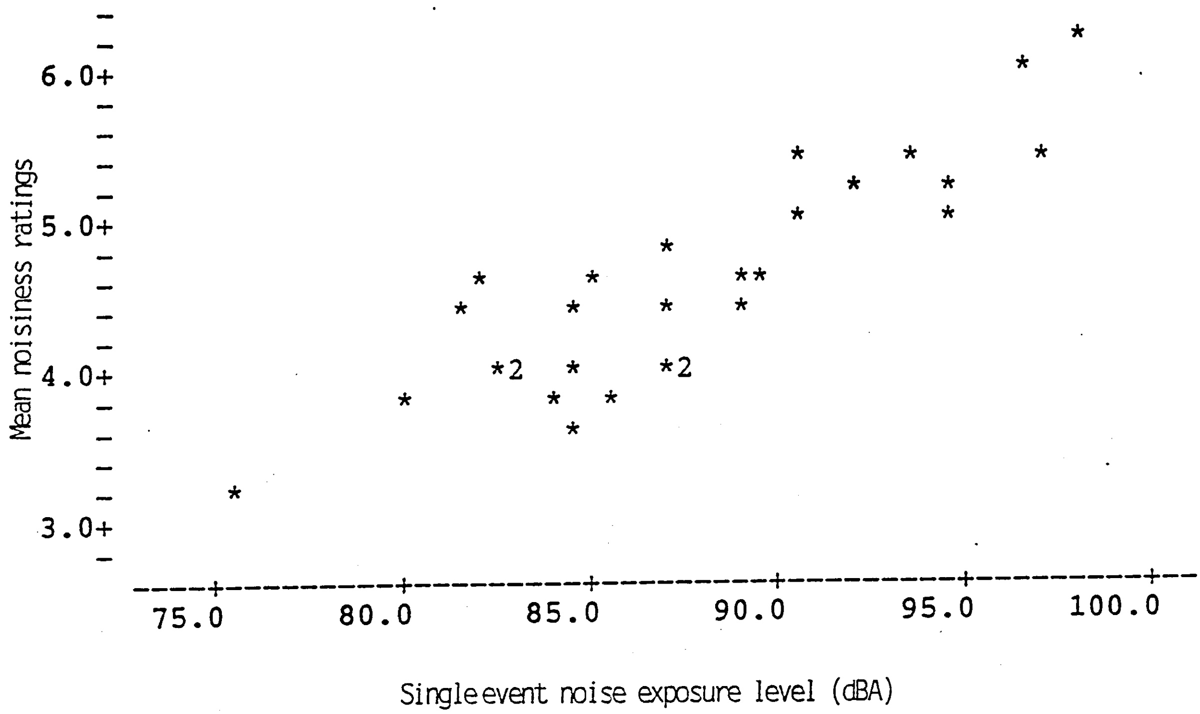


Figure Q.7 Mean noisiness ratings vs single event noise exposure level

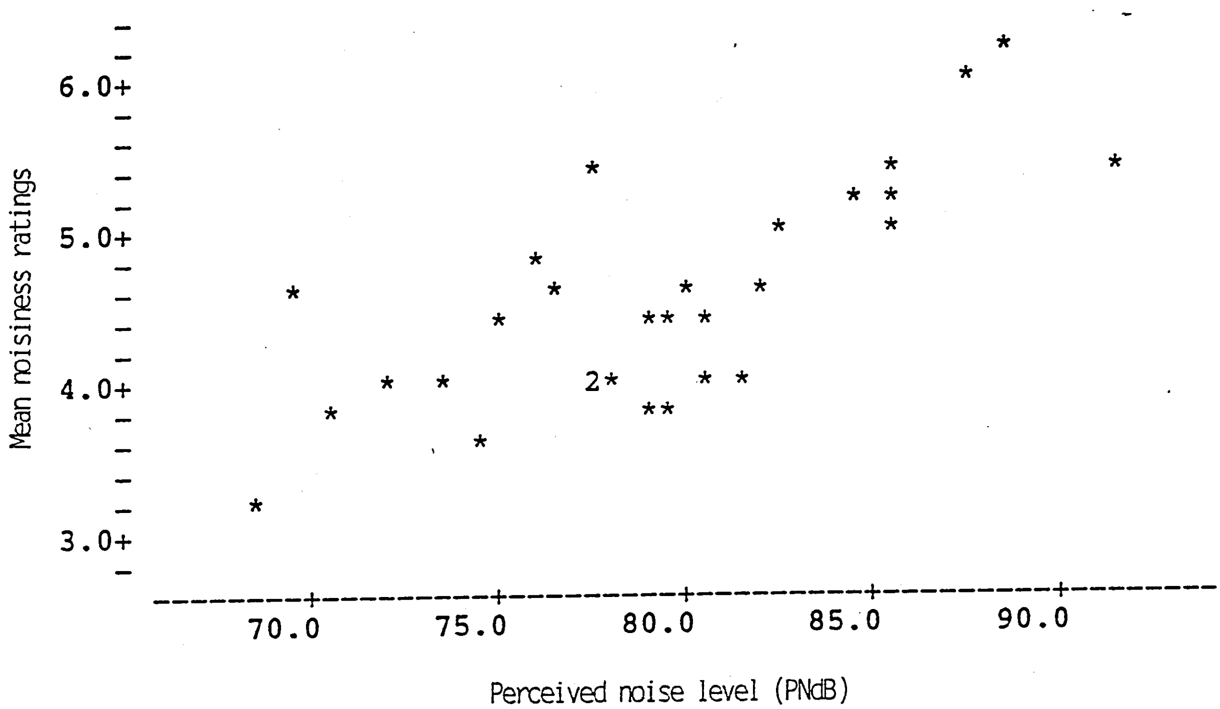


Figure Q.8 Mean noisiness ratings vs Perceived Noise Level

Appendix R

The percentage of responses for each category of annoyance and reasons for annoyance for each appliance type

R.1 Hair Dryers

Perceived annoyance of Hair dryers is shown in Table R.1

Table R.1 Perceived annoyance of Hair Dryers - Percentage of responses in each category.

Hair Dryers	L_{WA}	Not	A Little	Moderately	Extremely
HD 1	69	54.0	29.0	17.0	0.0
HD 2	71	25.0	46.0	29.0	0.0
HD 3	73	25.0	54.0	21.0	0.0
HD 4	74	33.3	33.3	33.3	0.0
HD 5	76	37.0	46.0	17.0	0.0
HD 6	78	0.0	13.0	71.0	16.0
HD 7	77	25.0	38.0	29.0	8.0
HD 8	80	21.0	42.0	37.0	0.0
HD 9	81	17.0	38.0	33.0	12.0
HD 10	82	8.0	29.0	46.0	17.0
HD 11	81	13.0	54.0	29.0	4.0
MEAN		23.0	38.0	33.0	6.0

Reasons for annoyance of Hair Dryers is shown in Table R.2

Table R.2 Reasons for annoyance of each Hair Dryer.

Appliance	1	2	3	4	5	6	7	Total Number
HD I	3	8						11
HD II	7	11						18
HD III	9	7	1		1			18
HD IV	11	2	1		2			16
HD V	10	4	1					15
HD VI	5	16	2			1		24
HD VII	8	9			1	1		19
HD VIII	9	8	2					19
HD IX	13	7						20
HD X	11	9	2					22
HD XI	13	6	1		1			21

Reasons for annoyance where:

1 = Noise level in general
2 = Peaks/high frequency content of noise
3 = Noise and mention of frequency content
4 = Low frequency noise
5 = Complaint about a mechanical aspect of the appliance
6 = Variation in the frequency content of the noise
7 = Dislike of the appliance in general

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex 722 Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Compact Hair Dryer - Speed 2

HD 5 - Braun 1200 Supercompact Hair Dryer - Speed 1

HD 6 - Moulinex 722 Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Supercompact Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Compact Hair Dryer - Speed 3

R.2 Vacuum Cleaners

Perceived annoyance of vacuum cleaners is shown in Table R.3

Table R.3 Perceived annoyance of Vacuum Cleaners - Percentage of responses in each category.

Vacuum Cleaners	L_{WA}	Not	A Little	Moderately	Extremely
VC 1	77	25.0	50.0	25.0	0.0
VC 2	79	37.0	42.0	21.0	0.0
VC 3	79	33.3	33.3	33.3	0.0
VC 4	80	25.0	29.0	42.0	4.0
VC 5	80	29.0	25.0	38.0	8.0
VC 6	82	25.0	25.0	46.0	4.0
VC 7	91	8.0	33.0	46.0	13.0
VC 8	88	0.0	8.0	25.0	67.0
MEAN		23.0	31.0	34.0	12.0

Reasons for annoyance of Vacuum Cleaners is shown in Table R.4

Table R.4 Reasons for annoyance of each Vacuum Cleaner.

Appliance	1	2	3	4	5	6	7	Total Number
VC I	14	1		1		1	1	18
VC II	9	2		1	2		1	15
VC III	10	3		1		1	1	16
VC IV	11	2	1		4			18
VC V	9	3	2		1	1		16
VC VI	14		1	2			1	18
VC VII	15	1	1		4	1		22
VC VIII	15		1	8				24

Reasons for annoyance where:

1 = Noise level in general
2 = Peaks/high frequency content of noise
3 = Noise and mention of frequency content
4 = Low frequency noise
5 = Complaint about a mechanical aspect of the appliance
6 = Variation in the frequency content of the noise
7 = Dislike of the appliance in general

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar C606 Supreme Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

R.3 Food Mixers

Perceived annoyance of Food Mixers is shown in Table R.5

Table R.5 Perceived annoyance of Food Mixers - Percentage of responses in each category.

Food Mixers	L_{WA}	Not	A Little	Moderately	Extremely
FM 1	69	8	25	50	17
FM 2	74	13	58	29	0
FM 3	75	17	33	33	17
FM 4	83	8	25	42	25
MEAN		11	35	39	15

Reasons for annoyance of Food Mixers is shown in Table R.6

Table R.6 Reasons for annoyance of each Food Mixer.

Appliance	1	2	3	4	5	6	7	Total Number
FM I	6	3	1	1	9		1	22
FM II	10	7	1		1		2	21
FM III	10		1		8	1		20
FM IV	18	2			2			22

Reasons for annoyance where:

1 = Noise level in general
2 = Peaks/high frequency content of noise
3 = Noise and mention of frequency content
4 = Low frequency noise
5 = Complaint about a mechanical aspect of the appliance
6 = Variation in the frequency content of the noise
7 = Dislike of the appliance in general

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini A345 Food Mixer - Speed 2

FM 3 - Philips HM3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef A901 Food Mixer - Speed 4 (medium)

R.4 Liquidisers

Perceived annoyance of Liquidisers is shown in Table R.7

Table R.7 Perceived annoyance of Liquidisers - Percentage of responses in each category.

Liquidiser	L_{WA}	Not	A Little	Moderately	Extremely
LIQ 1	76	8	17	50	25
LIQ 2	82	4	25	50	21
LIQ 3	85	8	42	42	8
LIQ 4	84	4	33	50	13
MEAN		6	29	48	17

Reasons for annoyance of Liquidisers is shown in Table R.8

Table R.8 Reasons for annoyance of each Liquidiser.

Appliance	1	2	3	4	5	6	7	Total Number
LIQ I	13	1	2	1	5			22
LIQ II	12	8	1		2			23
LIQ III	15	2	1		4			22
LIQ IV	10	11	2					23

Reasons for annoyance where:

1 = Noise level in general
2 = Peaks/high frequency content of noise
3 = Noise and mention of frequency content
4 = Low frequency noise
5 = Complaint about a mechanical aspect of the appliance
6 = Variation in the frequency content of the noise
7 = Dislike of the appliance in general

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef A901 with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

R.5 Food Processors

Perceived annoyance of Food Processors is shown in Table R.9

Table R.9 Perceived annoyance of Food Processors - Percentage of responses in each category.

Food Processor	L_{WA}	Not	A Little	Moderately	Extremely
FP 1	80	17.0	25.0	38.0	20.0
FP 2	87	0.0	5.0	33.0	62.0
FP 3	85	12.5	25.0	50.0	12.5
Mean		10.0	18.0	40.0	32.0

Reasons for annoyance of Food Processors is shown in Table R.10

Table R.10 Reasons for annoyance of each Food Processor.

Appliance	1	2	3	4	5	6	7	Total Number
FP I	8	12						20
FP II	7	16	1					24
FP III	8	12	1					21

Reasons for annoyance where:

```
1 = Noise level in general
2 = Peaks/high frequency content of noise
3 = Noise and mention of frequency content
4 = Low frequency noise
5 = Complaint about a mechanical aspect of the appliance
6 = Variation in the frequency content of the noise
7 = Dislike of the appliance in general
```

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor

Appendix S

Noisiness ratings vs annoyance ratings for each appliance type

S.1 Hair Dryers

The number of responses to the categories of noisiness and annoyance are shown in Table S.1 S.2

Table S.1 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
HD 1			
Not noisy	15	2	17
Quite noisy	3	1	4
Moderately noisy	2	0	2
Very noisy	0	1	1
HD 2			
Not noisy	11	2	13
Quite noisy	4	1	5
Moderately noisy	2	4	6
Very noisy	0	0	0
HD 3			
Not noisy	7	2	9
Quite noisy	9	0	9
Moderately noisy	3	3	6
Very noisy	0	0	0
HD 4			
Not noisy	9	2	11
Quite noisy	7	1	8
Moderately noisy	0	2	2
Very noisy	0	3	3
HD 5			
Not noisy	13	1	14
Quite noisy	4	1	5
Moderately noisy	3	2	5
Very noisy	0	0	0

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Hair Dryer - Speed 2

HD 5 - Braun 1200 Hair Dryer - Speed 1

HD 6 - Moulinex Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Hair Dryer - Speed 3

Table S.2 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
HD 6			
Not noisy	0	2	2
Quite noisy	2	6	8
Moderately noisy	0	8	8
Very noisy	1	5	6
HD 7			
Not noisy	10	2	12
Quite noisy	1	2	3
Moderately noisy	4	2	6
Very noisy	0	3	3
HD 8			
Not noisy	7	3	10
Quite noisy	5	3	8
Moderately noisy	3	2	5
Extremely noisy	0	1	1
HD 9			
Not noisy	4	1	5
Quite noisy	4	4	8
Moderately noisy	5	4	9
Very noisy	0	2	2
HD 10			
Not noisy	3	1	4
Quite noisy	4	5	9
Moderately noisy	2	5	7
Very noisy	0	4	4
HD 11			
Not noisy	6	2	8
Quite noisy	6	4	10
Moderately noisy	4	2	6
Very noisy	0	0	0

S.2 Vacuum Cleaners

The number of responses to the categories of noisiness and annoyance are shown in Table S.3 and S.4

Table S.3 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
VC 1			
Not noisy	6	0	6
Quite noisy	9	5	14
Moderately noisy	2	1	3
Very noisy	1	0	1
VC 2			
Not noisy	11	3	14
Quite noisy	4	1	5
Moderately noisy	4	1	5
Very noisy	0	0	0
VC 3			
Not noisy	10	3	13
Quite noisy	3	3	6
Moderately noisy	3	2	5
Very noisy	0	0	0
VC 4			
Not noisy	6	1	7
Quite noisy	5	7	12
Moderately noisy	2	1	3
Very noisy	0	2	2

Table S.4 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
VC 5			
Not noisy	8	2	10
Quite noisy	2	3	5
Moderately noisy	3	3	6
Very noisy	0	3	3
VC 6			
Not noisy	6	0	6
Quite noisy	4	4	8
Moderately noisy	1	5	6
Very noisy	1	3	4
VC 7			
Not noisy	0	0	0
Quite noisy	3	1	4
Moderately noisy	6	7	13
Very noisy	1	6	7
VC 8			
Not noisy	0	0	0
Quite noisy	0	0	0
Moderately noisy	2	2	4
Very noisy	0	20	20

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

S.3 Food Mixers

The number of responses to the categories of noisiness and annoyance are shown in Table S.5

Table S.5 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
FM 1			
Not noisy	2	2	4
Quite noisy	6	4	10
Moderately noisy	0	4	4
Very noisy	0	6	6
FM 2			
Not noisy	6	0	6
Quite noisy	8	1	9
Moderately noisy	3	5	8
Very noisy	0	1	1
FM 3			
Not noisy	5	1	6
Quite noisy	4	3	7
Moderately noisy	3	4	7
Very noisy	0	4	4
FM 4			
Not noisy	0	1	1
Quite noisy	2	3	5
Moderately noisy	3	8	11
Very noisy	3	4	7

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini Food Mixer - Speed 2

FM 3 - Philips HR3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef Food Mixer - Speed 4 (medium)

S.4 Liquidisers

The number of responses to the categories of noisiness and annoyance are shown in Table S.6

Table S.6 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
LIQ 1			
Not noisy	0	0	0
Quite noisy	3	0	3
Moderately noisy	2	11	13
Very noisy	1	7	8
LIQ 2			
Not noisy	1	0	1
Quite noisy	1	6	7
Moderately noisy	3	6	9
Very noisy	2	5	7
LIQ 3			
Not noisy	1	0	1
Quite noisy	5	2	7
Moderately noisy	4	4	8
Very noisy	2	6	8
LIQ 4			
Not noisy	0	0	0
Quite noisy	4	0	4
Moderately noisy	5	8	13
Very noisy	0	7	7

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

S.5 Food Processors

The number of responses to the categories of noisiness and annoyance are shown in Table S.7

Table S.7 Noisiness vs annoyance - Number of responses in each category.

Noisiness	Not annoying	Extremely annoying	ALL
FP 1			
Not noisy	4	3	7
Quite noisy	4	5	9
Moderately noisy	2	3	5
Very noisy	0	3	3
FP 2			
Not noisy	0	0	0
Quite noisy	1	0	1
Moderately noisy	0	6	6
Very noisy	0	17	17
FP 3			
Not noisy	0	0	0
Quite noisy	3	2	5
Moderately noisy	6	9	15
Very noisy	0	4	4

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor

Appendix T

Mean rating for each category of usefulness for each appliance type

T.1 Hair Dryers

The perceived usefulness of each hair drier can be seen in Table T.1.

Table T.1 Mean rating for each category of usefulness.

Hair Dryer	L_{WA}	Not Useful	A little	Moderately	Extremely
HD 1	69	2.50	3.57	3.20	3.30
HD 2	71	3.00	4.00	3.50	3.80
HD 3	73	3.00	4.14	3.63	4.17
HD 4	74	2.66	4.14	3.43	4.14
HD 5	76	3.00	3.70	3.63	3.50
HD 6	78	4.50	4.50	4.55	4.80
HD 7	77	3.67	4.00	4.13	3.50
HD 8	80	3.67	3.57	4.00	3.60
HD 9	81	3.80	5.13	4.14	4.25
HD 10	82	3.80	5.40	4.30	4.30
HD 11	81	3.50	4.18	4.40	3.75
MEAN		3.37	4.20	3.90	3.90

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex 722 Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Compact Hair Dryer - Speed 2

HD 5 - Braun 1200 Supercompact Hair Dryer - Speed 1

HD 6 - Moulinex 722 Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Supercompact Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Compact Hair Dryer - Speed 3

T.2 Vacuum Cleaners

The perceived usefulness of each vacuum cleaner can be seen in Table T.2.

Table T.2 Mean rating for each category of usefulness.

Vacuum Cleaner	L_{WA}	Not Useful	A little	Moderately	Extremely
VC 1	77		3.75	4.60	3.83
VC 2	79	6.00	5.00	3.67	3.30
VC 3	79			3.92	3.58
VC 4	80		4.50	4.00	4.20
VC 5	80		6.00	4.10	4.10
VC 6	82		4.50	4.22	4.73
VC 7	91	5.00	4.50	5.00	5.60
VC 8	88	6.00	6.00	6.00	6.25
MEAN		5.67	4.90	4.40	4.40

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar C606 Supreme Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

T.3 Food Mixers

The perceived usefulness for each food mixer is shown in Table T.3.

Table T.3 Mean rating for each category of usefulness.

Food Mixer	L_{WA}	Not Useful	A little	Moderately	Extremely
FM 1	69	4.70	4.124	4.600	5.0
FM 2	74	4.00	4.290	4.080	4.5
FM 3	75	4.60	4.080	4.500	5.0
FM 4	83	5.20	5.000	5.200	5.5
MEAN		4.625	4.370	4.595	5.0

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini A345 Food Mixer - Speed 2

FM 3 - Philips HM3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef A901 Food Mixer - Speed 4 (medium)

T.4 Liquidisers

The perceived usefulness of each liquidiser is shown in Table T.4.

Table T.4 Mean rating for each category of usefulness.

Liquidiser	L_{WA}	Not Useful	A little	Moderately	Extremely
LIQ 1	76	4.8300	5.100	5.4300	6.00
LIQ 2	82	4.5000	5.300	5.1000	5.00
LIQ 3	85	4.5000	5.200	4.7000	6.00
LIQ 4	84	5.0000	5.300	5.3000	6.00
MEAN		4.7075	5.225	5.1325	5.75

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef A901 with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

T.5 Food Processors

The perceived usefulness of each food processor is shown in Table T.5.

Table T.5 Mean rating for each category of usefulness.

Food Processor	L_{WA}	Not Useful	A little	Moderately	Extremely
FP 1	80	4.00	4.180	4.380	4.00
FP 2	87	5.80	5.800	5.600	6.50
FP 3	85	5.00	5.100	5.100	5.00
MEAN		4.93	5.027	5.027	5.17

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor

Appendix U

Acceptability ratings vs usefulness ratings for each type of appliance.

U.1 Hair Dryers

The number of responses to the categories of usefulness and acceptability for hair dryers can be seen in Table U.1 and Table U.2.

Table U.1 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
HD 1			
Not useful	9	3	12
Extremely useful	11	1	12
ALL	20	4	24
HD 2			
Not useful	6	4	10
Extremely useful	13	1	14
ALL	19	5	24
HD 3			
Not useful	7	3	10
Extremely useful	14	0	14
ALL	21	3	24
HD 4			
Not useful	6	4	10
Extremely useful	11	3	14
ALL	17	7	24
HD 5			
Not useful	7	3	10
Extremely useful	17	0	17
ALL	21	3	24
HD 6			
Not useful	4	6	10
Extremely useful	6	8	14
ALL	10	14	24

Table U.2 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
HD 7			
Not useful	7	3	10
Extremely useful	11	3	14
ALL	18	6	24
HD 8			
Not useful	8	1	9
Extremely useful	12	3	15
ALL	20	4	24
HD 9			
Not useful	7	6	13
Extremely useful	10	1	11
ALL	17	7	24
HD 10			
Not useful	7	6	13
Extremely useful	9	2	11
ALL	16	8	24
HD 11			
Not useful	10	2	12
Extremely useful	10	2	12
ALL	20	4	24

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex 722 Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Compact Hair Dryer - Speed 2

HD 5 - Braun 1200 Supercompact Hair Dryer - Speed 1

HD 6 - Moulinex 722 Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Supercompact Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Compact Hair Dryer - Speed 3

U.2 Vacuum Cleaners

The number of responses to the categories of usefulness and acceptability for vacuum cleaners can be seen in Table U.3 and U.4.

Table U.3 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
VC 1			
Not useful	3	1	4
Extremely useful	19	1	20
ALL	22	2	24
VC 2			
Not useful	2	0	2
Extremely useful	21	1	22
ALL	23	1	24
VC 3			
Not useful	0	0	0
Extremely useful	24	0	24
ALL	24	0	24
VC 4			
Not useful	1	1	2
Extremely useful	19	3	22
ALL	20	4	24

Table U.4 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
VC 5			
Not useful	0	1	1
Extremely useful	19	4	23
ALL	19	5	24
VC 6			
Not useful	3	1	4
Extremely useful	19	1	20
ALL	22	2	24
VC 7			
Not useful	2	1	3
Extremely useful	16	5	21
ALL	18	6	24
VC 8			
Not useful	2	2	4
Extremely useful	7	13	20
ALL	9	15	24

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar C606 Supreme Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

U.3 Food Mixers

The number of responses to the categories of usefulness and acceptability for food mixers can be seen in Table U.5.

Table U.5 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
FM 1			
Not useful	9	2	11
Extremely useful	6	7	13
ALL	15	9	24
FM 2			
Not useful	6	2	8
Extremely useful	15	1	16
ALL	21	3	24
FM 3			
Not useful	10	7	17
Extremely useful	5	2	7
ALL	15	9	24
FM 4			
Not useful	7	5	12
Extremely useful	8	4	12
ALL	15	9	24

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini A345 Food Mixer - Speed 2

FM 3 - Philips HM3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef A901 Food Mixer - Speed 4 (medium)

U.4 Liquidisers

The number of responses to the categories of usefulness and acceptability for liquidisers can be seen in Table U.6.

Table U.6 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
LIQ 1			
Not useful	8	7	15
Extremely useful	5	4	9
ALL	13	11	24
LIQ 2			
Not useful	8	5	13
Extremely useful	7	4	11
ALL	15	9	24
LIQ 3			
Not useful	8	6	14
Extremely useful	7	3	10
ALL	15	9	24
LIQ 4			
Not useful	12	4	16
Extremely useful	5	3	8
ALL	17	7	24

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef A901 with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

U.5 Food Processors

The number of responses to the categories of usefulness and acceptability for food processors can be seen in Table U.7.

Table U.7 Usefulness vs Acceptability - Number of responses in each category.

Usefulness	Acceptable	Not Acceptable	ALL
FP 1			
Not useful	9	5	14
Extremely useful	8	2	10
ALL	17	7	24
FP 2			
Not useful	5	9	14
Extremely useful	4	6	10
ALL	9	15	24
FP 3			
Not useful	9	4	13
Extremely useful	7	4	11
ALL	16	8	24

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor

Appendix V

Noisiness ratings vs acceptability ratings for each appliance type

V.1 Hair Dryers

The number of responses to the categories of noisiness and acceptability are shown in Table V.1 and V.2

Table V.1 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
HD 1			
Not noisy	16	1	17
Quite noisy	3	1	4
Moderately noisy	1	1	2
Very noisy	0	1	1
HD 2			
Not noisy	10	3	13
Quite noisy	5	0	5
Moderately noisy	4	2	6
Very noisy	0	0	0
HD 3			
Not noisy	8	1	9
Quite noisy	8	1	9
Moderately noisy	5	1	6
Very noisy	0	0	0
HD 4			
Not noisy	9	2	11
Quite noisy	6	2	8
Moderately noisy	1	1	2
Very noisy	1	2	3
HD 5			
Not noisy	13	1	14
Quite noisy	4	1	5
Moderately noisy	4	1	5
Very noisy	0	0	0

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Hair Dryer - Speed 2

HD 5 - Braun 1200 Hair Dryer - Speed 1

HD 6 - Moulinex Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Hair Dryer - Speed 3

Table V.2 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
HD 6			
Not noisy	2	0	2
Quite noisy	4	4	8
Moderately noisy	4	4	8
Very noisy	10	6	6
HD 7			
Not noisy	11	1	12
Quite noisy	2	1	3
Moderately noisy	4	2	6
Very noisy	1	2	3
HD 8			
Not noisy	9	1	10
Quite noisy	6	2	8
Moderately noisy	5	0	5
Extremely noisy	0	1	0
HD 9			
Not noisy	4	1	5
Quite noisy	6	2	8
Moderately noisy	7	2	9
Very noisy	0	2	2
HD 10			
Not noisy	4	0	4
Quite noisy	7	2	9
Moderately noisy	4	3	7
Very noisy	1	3	4
HD 11			
Not noisy	7	1	8
Quite noisy	9	1	10
Moderately noisy	4	2	6
Very noisy	0	0	0

V.2 Vacuum Cleaners

The number of responses to the categories of noisiness and acceptability are shown in Table V.3 and V.4

Table V.3 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
VC 1			
Not noisy	6	0	6
Quite noisy	12	2	14
Moderately noisy	3	0	3
Very noisy	1	0	1
VC 2			
Not noisy	13	1	14
Quite noisy	5	0	5
Moderately noisy	5	0	5
Very noisy	0	0	0
VC 3			
Not noisy	13	0	13
Quite noisy	6	0	6
Moderately noisy	5	0	5
Very noisy	0	0	0
VC 4			
Not noisy	7	0	7
Quite noisy	9	3	12
Moderately noisy	3	0	3
Very noisy	1	1	2

Table V.4 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
VC 5			
Not noisy	10	0	10
Quite noisy	5	0	5
Moderately noisy	3	3	6
Very noisy	1	2	3
VC 6			
Not noisy	6	0	6
Quite noisy	8	0	8
Moderately noisy	5	1	6
Very noisy	3	1	4
VC 7			
Not noisy	0	0	0
Quite noisy	4	0	4
Moderately noisy	9	4	13
Very noisy	5	2	7
VC 8			
Not noisy	0	0	0
Quite noisy	0	0	0
Moderately noisy	2	2	4
Very noisy	7	13	20

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

V.3 Food Mixers

The number of responses to the categories of noisiness and acceptability are shown in Table V.5

Table V.5 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
FM 1			
Not noisy	4	0	4
Quite noisy	9	1	10
Moderately noisy	2	2	4
Very noisy	0	6	6
FM 2			
Not noisy	6	0	6
Quite noisy	9	0	9
Moderately noisy	5	3	8
Very noisy	1	0	1
FM 3			
Not noisy	6	0	6
Quite noisy	5	2	7
Moderately noisy	3	4	7
Very noisy	1	3	4
FM 4			
Not noisy	1	0	1
Quite noisy	3	2	5
Moderately noisy	8	3	11
Very noisy	3	4	7

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini Food Mixer - Speed 2

FM 3 - Philips HR3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef Food Mixer - Speed 4 (medium)

V.4 Liquidisers

The number of responses to the categories of noisiness and acceptability are shown in Table V.6

Table V.6 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
LIQ 1			
Not noisy	0	0	0
Quite noisy	2	1	3
Moderately noisy	9	4	13
Very noisy	2	6	8
LIQ 2			
Not noisy	0	1	1
Quite noisy	6	1	7
Moderately noisy	6	3	9
Very noisy	3	4	7
LIQ 3			
Not noisy	1	0	1
Quite noisy	6	1	7
Moderately noisy	4	4	8
Very noisy	4	4	8
LIQ 4			
Not noisy	0	0	0
Quite noisy	4	0	4
Moderately noisy	9	4	13
Very noisy	4	3	7

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

V.5 Food Processors

The number of responses to the categories of noisiness and acceptability are shown in Table V.7

Table V.7 Noisiness vs acceptability - Number of responses in each category.

Noisiness	Acceptable	Not Acceptable	ALL
FP 1			
Not noisy	5	2	7
Quite noisy	8	1	9
Moderately noisy	3	2	5
Very noisy	1	2	3
FP 2			
Not noisy	0	0	0
Quite noisy	1	0	1
Moderately noisy	4	2	6
Very noisy	4	13	17
FP 3			
Not noisy	0	0	0
Quite noisy	5	0	5
Moderately noisy	9	6	15
Very noisy	2	2	4

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor

Appendix W

Acceptability ratings vs annoyance ratings for each type of appliance

W.1 Hair Dryers

The number of responses to the categories of acceptability and annoyance are shown in Table W.1 and W.2

Table W.1 Acceptability vs annoyance - Number of responses in each category.

Annoyance	Acceptable	Not Acceptable	ALL
HD 1			
Not annoying	19	1	20
Extremely annoying	1	3	4
ALL	20	4	24
HD 2			
Not annoying	15	2	17
Extremely annoying	4	3	7
ALL	19	5	24
HD 3			
Not annoying	18	1	19
Extremely annoying	3	2	5
ALL	21	3	24
HD 4			
Not annoying	14	2	16
Extremely annoying	3	5	8
ALL	17	7	24
HD 5			
Not annoying	19	1	20
Extremely annoying	2	2	4
ALL	21	3	24
HD 6			
Not annoying	2	1	3
Extremely annoying	8	13	21
ALL	10	14	24

Table W.2 Acceptability vs annoyance - Number of responses in each category.

Annoyance	Acceptable	Not Acceptable	ALL
HD 7			
Not annoying	13	2	15
Extremely annoying	5	4	9
ALL	18	6	24
HD 8			
Not annoying	13	2	15
Extremely annoying	7	2	9
ALL	20	4	24
HD 9			
Not annoying	11	2	13
Extremely annoying	6	5	11
ALL	17	7	24
HD 10			
Not annoying	9	0	9
Extremely annoying	7	8	15
ALL	16	8	24
HD 11			
Not annoying	16	0	16
Extremely annoying	4	4	8
ALL	20	4	24

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex 722 Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Compact Hair Dryer - Speed 2

HD 5 - Braun 1200 Supercompact Hair Dryer - Speed 1

HD 6 - Moulinex 722 Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Supercompact Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Compact Hair Dryer - Speed 3

W.2 Vacuum Cleaners

The number of responses to the categories of acceptability and annoyance are shown in Table W.3 and W.4.

Table W.3 Acceptability vs annoyance - Number of responses in each category .

Annoyance	Acceptable	Not Acceptable	ALL
VC 1			
Not annoying	18	0	10
Extremely annoying	4	2	6
ALL	22	2	24
VC 2			
Not annoying	18	1	19
Extremely annoying	5	0	5
ALL	23	1	24
VC 3			
Not annoying	16	0	16
Extremely annoying	8	0	8
ALL	24	0	24
VC 4			
Not annoying	13	0	13
Extremely annoying	7	4	11
ALL	20	4	24

Table W.4 Acceptability vs annoyance - Number of responses in each category .

Annoyance	Acceptable	Not Acceptable	ALL
VC 5			
Not annoying	13	0	13
Extremely annoying	6	5	11
ALL	19	5	24
VC 6			
Not annoying	12	0	12
Extremely annoying	10	2	12
ALL	22	2	24
VC 7			
Not annoying	10	0	10
Extremely annoying	8	6	14
ALL	18	6	24
VC 8			
Not annoying	2	0	2
Extremely annoying	7	15	22
ALL	9	15	24

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar C606 Supreme Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

W.3 Food Mixers

The number of responses to the categories of acceptability and annoyance are shown in Table W.5

Table W.5 Acceptability vs Annoyance - Number of responses in each category.

Annoyance	Acceptable	Not Acceptable	ALL
FM 1			
Not annoying	8	0	8
Extremely annoying	7	9	16
ALL	15	9	24
FM 2			
Not annoying	16	1	17
Extremely annoying	21	3	24
ALL	21	3	24
FM 3			
Not annoying	9	3	12
Extremely annoying	6	6	12
ALL	15	9	24
FM 4			
Not annoying	7	1	8
Extremely annoying	8	8	16
ALL	15	9	24

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini A345 Food Mixer - Speed 2

FM 3 - Philips HM3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef A901 Food Mixer - Speed 4 (medium)

W.4 Liquidisers

The number of responses to the categories of acceptability and annoyance are shown in Table W.6

Table W.6 Acceptability vs Annoyance - Number of responses in each category.

Annoyance	Acceptable	Not Acceptable	ALL
LIQ 1			
Not annoying	5	1	6
Extremely annoying	8	10	18
ALL	13	11	24
LIQ 2			
Not annoying	5	2	7
Extremely annoying	10	7	17
ALL	15	9	24
LIQ 3			
Not annoying	11	1	12
Extremely annoying	4	8	12
ALL	15	9	24
LIQ 4			
Not annoying	8	1	9
Extremely annoying	9	6	15
ALL	17	7	24

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef A901 with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

W.5 Food Processors

The number of responses to the categories of acceptability and annoyance are shown in Table W.7

Table W.7 Acceptability vs Annoyance - Number of responses in each category.

Annoyance	Acceptable	Not Acceptable	ALL
FP 1			
Not annoying	10	0	10
Extremely annoying	7	7	14
ALL	17	7	24
FP 2			
Not annoying	1	0	1
Extremely annoying	8	15	23
ALL	9	15	24
FP 3			
Not annoying	7	2	9
Extremely annoying	9	6	15
ALL	16	8	24

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3Food Processor

Appendix X

Usefulness ratings vs annoyance ratings for each type of appliance.

X.1 Hair Dryers

The number of responses to the categories of usefulness annoyance for hair dryers can be seen in Table X.1.

Table X.1 Usefulness vs Annoyance - Number of responses in each category.

Usefulness	Not very annoying	Extremely annoying	ALL
HD 1			
Not useful	8	4	12
Extremely useful	12	0	12
HD 2			
Not useful	4	6	10
Extremely useful	13	1	14
HD 3			
Not useful	5	5	10
Extremely useful	14	0	14
HD 4			
Not useful	4	6	10
Extremely useful	12	2	14
HD 5			
Not useful	6	4	10
Extremely useful	14	0	14
HD 6			
Not useful	2	8	10
Extremely useful	1	13	14
HD 7			
Not useful	5	5	10
Extremely useful	10	4	14
HD 8			
Not useful	6	3	9
Extremely useful	9	6	15
HD 9			
Not useful	6	7	13
Extremely useful	7	4	11
HD 10			
Not useful	3	10	13
Extremely useful	6	5	11
HD 11			
Not useful	8	4	12
Extremely useful	8	4	12

The HD codes represent the following appliances:

HD 1 - Boots MD2 Hair Dryer - Speed 1

HD 2 - Moulinex 722 Beauty Styler Hair Dryer - Speed 1

HD 3 - Ronson Hotshot Hair Dryer - Speed 1

HD 4 - Braun 1500 Compact Hair Dryer - Speed 2

HD 5 - Braun 1200 Supercompact Hair Dryer - Speed 1

HD 6 - Moulinex 722 Beauty Styler Hair Dryer - Speed 2

HD 7 - Boots MD2 Hair Dryer - Speed 2

HD 8 - Clairol 1200 Hair Dryer - Speed 1

HD 9 - Braun 1200 Supercompact Hair Dryer - Speed 2

HD 10 - Ronson Hotshot Hair Dryer - Speed 2

HD 11 - Braun 1500 Compact Hair Dryer - Speed 3

X.2 Vacuum Cleaners

The number of responses to the categories of usefulness annoyance for Vacuum Cleaners can be seen in Table X.2.

Table X.2 Usefulness vs Annoyance - Number of responses in each category.

Usefulness	Not very annoying	Extremely annoying	ALL
VC 1			
Not useful	2	2	4
Extremely useful	16	4	20
VC 2			
Not useful	2	0	2
Extremely useful	17	5	22
VC 3			
Not useful	0	0	0
Extremely useful	16	8	24
VC 4			
Not useful	1	1	2
Extremely useful	12	10	22
VC 5			
Not useful	0	1	1
Extremely useful	13	10	23
VC 6			
Not useful	2	2	4
Extremely useful	10	10	20
VC 7			
Not useful	2	1	3
Extremely useful	8	13	21
VC 8			
Not useful	1	3	4
Extremely useful	1	19	20

The VC codes represent the following appliances:

VC 1 - Electrolux 520S Vacuum Cleaner

VC 2 - Electrolux ZA65 Vacuum Cleaner

VC 3 - Electrolux 350E Vacuum Cleaner

VC 4 - Kerstar C606 Supreme Vacuum Cleaner

VC 5 - Electrolux 345 Vacuum Cleaner

VC 6 - Electrolux 350E Vacuum Cleaner - Super Boost

VC 7 - Hoover 119 Vacuum Cleaner

VC 8 - Hoover U2002 Vacuum Cleaner

X.3 Food Mixer

The number of responses to the categories of usefulness annoyance for Food Mixers can be seen in Table X.3.

Table X.3 Usefulness vs Annoyance - Number of responses in each category.

Usefulness	Not very annoying	Extremely annoying	ALL
FM 1			
Not useful	7	4	11
Extremely useful	1	8	12
FM 2			
Not useful	7	1	8
Extremely useful	10	6	16
FM 3			
Not useful	9	8	17
Extremely useful	3	4	7
FM 4			
Not useful	5	7	12
Extremely useful	3	9	12

The FM codes represent the following appliances:

FM 1 - Philips HR1907 Food Mixer - Speed 1

FM 2 - Kenwood Mini A345 Food Mixer - Speed 2

FM 3 - Philips HM3060 Food Mixer - Speed 1

FM 4 - Kenwood Chef A901 Food Mixer - Speed 4 (medium)

X.4 Liquidisers

The number of responses to the categories of usefulness annoyance for Liquidisers can be seen in Table X.4.

Table X.4 Usefulness vs Annoyance - Number of responses in each category.

Usefulness	Not very annoying	Extremely annoying	ALL
LIQ 1			
Not useful	3	12	15
Extremely useful	3	6	9
LIQ 2			
Not useful	5	8	13
Extremely useful	2	9	11
LIQ 3			
Not useful	6	8	14
Extremely useful	6	4	10
LIQ 4			
Not useful	6	10	16
Extremely useful	3	5	8

The LIQ codes represent the following appliances:

LIQ 1 - Philips TX2000 Liquidiser - Speed 1

LIQ 2 - Moulinex 530 Liquidiser

LIQ 3 - Kenwood Chef A901 with Liquidiser Attachment - Speed 4

LIQ 4 - Moulinex 241.1 Liquidiser

X.5 Food Processors

The number of responses to the categories of usefulness annoyance for food processors can be seen in Table X.5.

Table X.5 Usefulness vs Annoyance - Number of responses in each category.

Usefulness	Not very annoying	Extremely annoying	ALL
FP 1			
Not useful	5	9	14
Extremely useful	5	5	10
FP 2			
Not useful	1	13	14
Extremely useful	0	10	10
FP 3			
Not useful	6	7	13
Extremely useful	3	8	11

The FP codes represent the following appliances:

FP 1 - Prestige L2001 Food Processor

FP 2 - Braun MC-1 Food Processor

FP 3 - Robot Chef RC3 Food Processor